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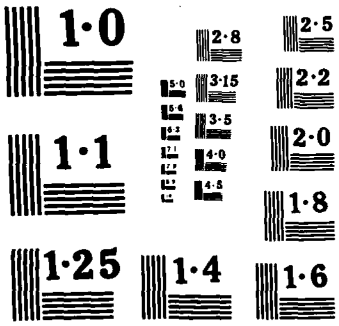

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CONFLAGRATION ANALYSIS SYSTEM II:

BIBLIOGRAPHY

Final Report

for

Federal Emergency Management Agency, Washington, D.C. 20472

FEMA Award Number EMW-C-0743

FEMA Work Unit Number 6141A

April 1985

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Final Report

by

Harry Hickey

for

Federal Emergency Management Agency, Washington, D.C. 20472

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International Association of Fire Chiefs, Inc.
1329 18th Street, N.W.
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CONFLAGRATION, MASS FIRE, FIRE SPREAD ANALYSIS, EMERGENCY MANAGEMENT, FIRE PROTECTION MASTER PLANNING, URBAN REDEVELOPMENT, FIRE DEPARTMENT.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report contains an annotated bibliography of the literature search conducted in support of Conflagration Analysis: System II. It is divided into two phases. Phase I discusses the literature reviewed to explore fire spread *within* a city block. Phase II reviews the literature examined for fire spread *between* city blocks. [illegible] include,

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TABLE OF CONTENTS

Phase I	Page
Bibliography	1-1
Literature Search	1-4
Annotated Bibliography	1-16

Phase II	Page
Bibliography	2-1
Literature Search	2-4
Annotated Bibliography	2-14

BIBLIOGRAPHY

Phase I

1. Ambrose, Joh E., Lester A. Eggleston and Calvin H. Yuill. The Use of Models for the Investigation of Fire Spread. San Antonio, (TX): Southwest Research Institute, 1965.

2. American Association for the Advancement of Science. Fire Safety and Disaster Preparedness. Washington, (DC): American Association for the Advancement of Science. Publication No. 79-R-3. 1979

3. Ball, J. A. and L. M. Pietrazak. "Investigation to Improve the Effectiveness of Water in the Suppression of Compartment Fires." Santa Barbara, (CA): Mission Research Corporation, 1978.

4. Berlin, Geoffrey N. "A Simulation Model of Fire Hazards." Boston, (MA): National Fire Protection Association, 1977 (Meeting Report).

5. Butler, C. P. Measurement of the Dynamics of Structural Fires. Menlo Park, (CA): Stanford Research Institute, August 1970.

6. Coward, Sara K., A Simulation Method for Estimating the Distribution of Fire Severities in Office Rooms. Borehamwood, (EG): Fire Research Station, 1975.

7. Defense Civil Preparedness Agency: Disaster Operations, A Handbook for Local Governments. Washington, (DC): Defense Civil Preparedness Agency, July 1972.

8. Department of Defense, Office of Civil Defense. Local Assessment of the Conflagration Potential of Urban Areas. Washington, (DC): Department of Defense, 1969.

9. Eggleston, Lester. Fire Defense Systems Analysis. (Application of Concepts to the San Jose Metropolitan Area. (Final Report) Sant Antonio, (TX): Southwest Research Institute, 1970.

10. Fang, Jim B. Fire Buildup in a Room and the Role of Interior Finish Materials. Washington, (DC): National Bureau of Standards, 1975.

11. Gomberg, Alan, "A Study of the Validity of Occupancy Hazard Classifications in Sprinklered Occupancies, and a Proposed Method for Occupancy Hazard Determination." (Unpublished Report - University of Maryland 1965).

12. Foster, Harold D. Disaster Planning - The Preservation of Life and Property New York, (NY): Springer - Verlag, 1980.

13. Insurance Services Office. Fire Suppression Rating Schedule. (Section 300 - Needed Fire Flow) New York, (NY): Insurance Services Office, 1980.

14. Kohlhammer, W. Determination of the Fire Protection Class of Industrial Structures. Dormagen, Germany: Fire Protection, German Journal of Fire Departments, 1970.

15. Lee, B. T. Modeling Individual and Multiple Building Fires. Menlo Park, (CA): Stanford Research Institute, 1972.

16. Lerup, Lars, David Cronrath, John Kon Chiang Liu. Learning From Fire: A Fire Protection Primer for Architects. Berkely, (CA): Center for Planning and Development Research, 1977.

17. Lie, T. T. Fire and Buildings. London: Applied Science Publishers, 1972.

18. McGuire, J. H. "Fire and the Spacial Separation of Buildings," Fire Technology, Vol. 1., No. 4, November 1965.

19. Miller, R. Keith, Milton E. Jenkins and James A. Keller. Analysis of Four Models of the Nuclear Caused Ignitions and Early Fires in Urban Areas. Albuquerque, (NM): The Dikewood Corporation, 1970

20. National Fire Protection Association. Conflagrations in America Since 1900. Boston, (MA): National Fire Protection Association, 1971 reprint.

21. Quintiere, Jame G. "An Overview of Fire Modeling," (Unpublished Paper presented to the Society of Fire Protection Engineers Meeting in March 1981)

22. Quintiere, James, "The Spread of Fire from a Compartment - A Review." Design of Buildings for Fire Safety. ASTM STP 685, American Society of Testing Materials, 1979.

23. Riegal, Robert, "Measurement of Fire Hazard." Pittsburgh, (PA): Institute of Fire Insurance, 1970.

24. Roberts, Charles F. "The Computation of Fuel and Fire Danger Parameters Using a Pocket Calculator," Fire Management Notes. Spring 1976, p. 11.

25. Salzberg, Frederic, Fire Department Operations Analysis. Chicago: Illinois Institute of Technology (OCD Work Unit 2522F), 1970.

26. Takata, Arthur N. Fire Spread Model Adoptation. Chicago, (IL): Illinois Institute of Technology, Research Institute of Technology, 1972.

27. Tammanini, Francesco, Calculations and Experiments on the Turbulent Burning of Vertical Walls in Single and Parallel Configurations. Norwood, (MA): Factory Mutual Research, 1979.

28. Thomas, P. H. and M. L. Bullen (et al) "Flashover and Instability in Fire Behavior," Combustion and Flame, 38: 159-171 (1980)

29. Vodvarka, Frank J. Urban Burns - Full Scale Field Studies. Chicago, (IL): Illinois Institute of Technology Research Institute, Final Technical Report - Project J6171, 1970.

30. Vodvarka, Frank J. Full-Scale Burns in Urban Areas - Part I - Fire Spread Between Structures. Chicago: Illinois Institute of Technology, Research Institute, 1969.

Supplements:

31. Labes, Willis G. Operations, Research Study - Extinguishment of Building Fires. Chicago, (IL): IIT Research Center, 1966.

32. Miller, Carl F. Fire Fighting Operations in Hamburg, Germany During World War II. Wahsington: (DC): Department of Defense 1975.

33. Weisbecker, Leo W. and Hong Lee, Evaluation of Systems Fire Development. Menlo Park, (CA): Stanford Research Institute, 1970.

Literature Synopsis

ι. Overview:

The literature reviewed todate on fire development in structures is ery impressive. A great deal of work has been accomplished on the fire ;rowth phenomena with structures over the past fifteen years. This esearch divides along the lines of fire growth within structures and fire ;rowth between structures. Probably most important is an expanded list of ariables that impact on the growth phenomena associated with structural ires.

Table 1 depicts a developed matrix between the identified variables and the literature sources. The Gage-Babcock Conflagration Model is included in the tabulation for comparative purposes. Therefore, it is important to examine both the reinforcement and the supplemental considerations for the quantitative methods for conflagration potential analysis.

This literature summary broadly annotates the reference source documents. Applicable formulas are discussed in the primary study document. This material examines quantitatvive modifications to the current conflagration assessmetn methodology. As this portion of the study becomes refined and the meaningful quantitative factors for conflagration analysis are determined, the relevatn literature will be brought into the mainstream of the study document.

3. Fire Development in Structures

Literally all of the literature reviewed to date relates to the fire development in structures. Therefore, for purposes of concrete examination, the itle must be narrowed to a more descriptive function. Basically there is concern over how fire develops within structures. The time - development phase is an important consideration to the potential spread of fire from one structure to another.

a. Specific heat of the fuel			X	X		X				X							X				X	X				X		X		
b. Ignition temperature of the fuel			X	X					X	X					X		X				X	X				X		X		
c. Rate of heat transfer to the unburned fuel			X	X						X					X		X				X	X				X		X		
d. Rate of heat loss from the unburned fuel			X	X						X					X		X				X	X				X		X		
e. Fuel load			X	X		X		X	X	X			X		X		X				X	X	X		X	X		X		
f. Fuel arrangement/fuel separation			X			X			X	X					X		X				X	X			X	X		X		
2. Construction Factor	X	X	X	X	X		X	X	X		X		X	X	X	X		X		X		X	X		X		X		X	X
a. Roof Construction				X				X					X		X							X	X		X				X	X
b. Floor Construction				X				X					X		X							X	X		X				X	X
c. Perimeter construction				X				X	X				X		X			X					X				X		X	X
1) Each wall face				X									X		X			X									X			
a) Length, Height/Openings													X		X			X									X			
b) Surface factor								X					X		X			X									X			
3. Structural Arrangement	X	X	X	X	X		X	X	X				X	X	X	X		X	X	X			X		X		X		X	X
a. Exposure factor for all sides					X										X												X			
1) Distance					X								X		X								X				X			
b. Height ratio					X			X	X				X		X								X				X		X	X
c. Ground floor area			X	X	X			X							X		X						X							
d. Attic spaces															X								X							
e. Exterior extensions such as balconies															X								X							
f. Faulty chase construction													X		X								X							
g. Integrity factor															X								X							
4. Block Configuration								X			X								X	X										
a. Density of fuel matrix								X	X				X																	
b. Slope								X	X														X							
c. Exposure factor all sides					X			X	X									X							X					
5. Environmental Factor		X					X	X	X		X									X					X				X	X
a. Contiguous block ratings								X											X											
b. Fire Spread velocity																	X		X						X					
c. Weather index																														
d. Fire Break Width		X			X			X	X		X		X						X						X					
e. Area Fire Flow													X										X		X				X	X
f. Fire Apparatus Density (units per square mile)													X												X				X	X
1) Primary area 1 to 5 miles													X												X				X	X
2) Secondary area 5 to 15 miles													X												X				X	X
3) Remote area 15 to 50 miles													X												X				X	X

In relation to mass fire or conflagration development, it appears ›ropriate to examine the post flashover case. Non flashover situations ›bably will not influence the parameters under consideration for the jor fire. Still the literature on this matter is significant.

The fundamental references to consider include the literature :hored by Amborse, Butler, Eggleston, Lee, Miller, Quintiere and Salzberg.

The essential parameters identified include (1) room geometry, (2) el geometry, (3) ignition source, (4) structural classification, (5) height i area of the building of origin, (6) ventilation conditions, and ›bably the most identified variable, (7) fuel loading. The interaction these variables in a post flashover situation can be interrelated to semble a predictive picture of fire spread beyond the point of origin.

The methods of analysis do vary considerably. This observation quires that a comparative analysis be structured to specifically evaluate e measures that contribute to fire development in the post flashover stage. e central tendency is to examine this issue as a function of the time temperature curve. The analytical interdepdendency of values will be ›orted in the supplemental paper dealing specifically with quantitative thods.

Fire Development in Multiple Structures

From a purely analytical view, the research identified in the literature fire development in multiple structures has been limited primarily to the nsiderations associated with wartime type fire propogation phenomena. Work nducted under the Office of Civil Defense grants at the Illinois Institute Technology, Southwest Research, Stanford Research, Mission Research, and reheamwood in England, do provide some important clues to this concern.

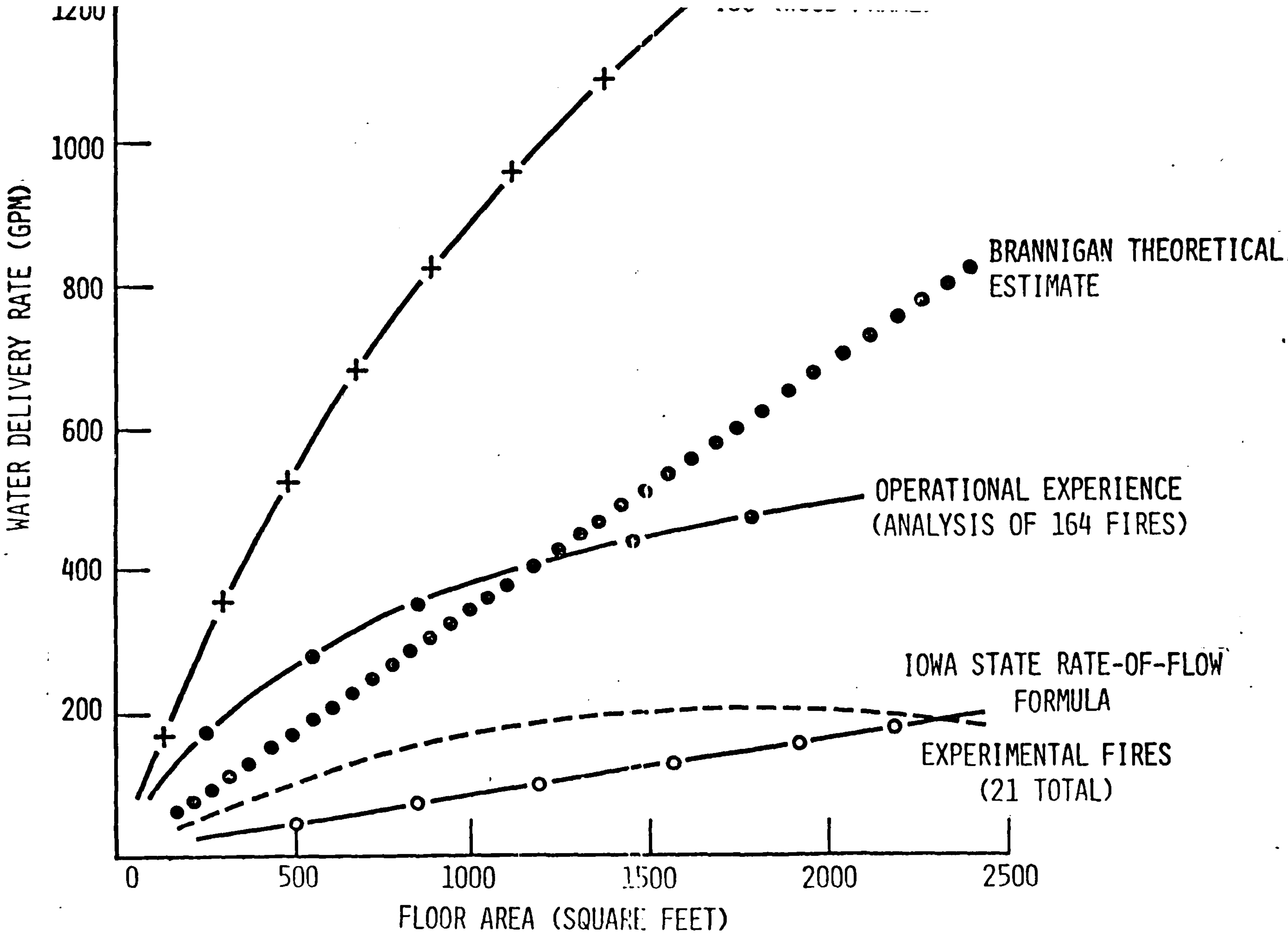
A close scruiteny of the literature reveals that a consistent set of :ables emerge when considering fire propogation among and between :iple structures. The vairables include: (1) wall area and thickness, wall separation distances, (3) wall height relationships, (4) wall ıing configurations, (5) area built upon, (6) flame progression ɔcity between structures, (7) height to area relationships, and (8) ermediate boundary separations. The variables identified have been eralized into "effective" parameters for the assessment of alternatives.

There is no question but that the Gage-Babock Conflagration hodology developed in the middle 1960's present the most comprehensive roach to the assessment of these identified variables. At this point time there is simply a need to reassess the quantitative impact of h variable in the stated study in light of new knowledge and to determine there is a requirement to specify new measurement values for each iable in the current methodology.

Conflagration Development

There appears to be three important documents to consider in the rent assessment of conflagrations. The source documents originate with the National Fire Protection Association, (2) The National Board of e Underwriters, and (3) the previously referenced Gag-Babcock Method Conflagration Analysis.

Historically, the National Fire Protection Association must be dited with tracking the influence and the calamity associated with flagrations. The variables identified in the conflagration reports of s organization are repeated through the remaining literature associated h this condition. Not suprising, these conditions can be summarized as lows: (1) congestion of high fire loadings, (2) inadequate separations



WATER DELIVERY RATE (GPM)
1200
1000
800
600
400
200
0
500
1000
1500
2000
2500
FLOOR AREA (SQUARE FEET)
BRANNIGAN THEORETICAL ESTIMATE
OPERATIONAL EXPERIENCE (ANALYSIS OF 164 FIRES)
IOWA STATE RATE-OF-FLOW FORMULA
EXPERIMENTAL FIRES (21 TOTAL)

Figure 1.

flagration Analysis Study

rt Description: Using a physically-based computer simulation of compart-
t fires, characteristics of the water spray from hose nozzle systems
d by the fire service are varied and the effect on fire knockdown per-
nance compared. The objective is to improve hose-nozzle performance to
ieve more effective fire control with smaller water usage and damage
with tolerable levels of high temperature steam over a wide range of
lding and fire conditions. A description of the computer simulation's
oretical and empirical basis is provided. The unique feature of the
ulation is that it not only models fire growth from flashover through
ree burning phase, but also follows the fire history through the period of
er application to either knockdown of the fire or burnout. It is then
onstrated how the computer simulation can be used to identify building
fire conditions most likely to stress the technology and also to esti-
e a preliminary set of near optimal water spray characteristic perfor-
ce goals. These results then provide a basis for future hardware
elopment and experimental testing.

le: Investigation to Improve the Effectiveness of Water in the Suppression of Compartment Fires

hor: J. A. Ball and L. M. Pietrazak

anization: Mission Research Corporation

liographical Data: J. A. Ball and L. M. Pietrzak, "Investigation to Improve the Effectiveness of Water in the Suppression of Compartment Fires," Prepared at Mission Research Corporation, Santa Barbara, California and delivered to a Combustion Institute meeting at Drexel University, Philadelphia, Pennsylvania, November 18, 1976. (RANN Contract No. C961)

mary:

Figure 1 displays several generalized estimates of required water
ivery rates for control of residential fires, plotted as a function of
olved fire area, which illustrate present knowledge. The ISO (Insurance
vices Office) curve though based upon operational experience is very con-
vative and probably represents worst cases. An actual average is repre-
ted by the curve labeled operational experience. By contrast the much
er water requirements obtained from experimental fires must reflect the
ence of many of the difficulties and uncertainties of operational fire
hting. Two simple theoretical estimates, both proportional to floor area,
shown. The Brannigan estimate demands a rate of water flow sufficient
cooling based upon the assumption that 80 percent of the heat content
the fuel is evolved in twenty minutes. The Iowa State formula requires
ooling rate sufficient to cool, within 30 seconds, the heat generated by
sumption of all the oxygen in the compartment volume. The wide diversity
these estimates may reflect the inherent uncertainties in the problem,
they are also attributable to the coarseness of the description which
empts to relate required water flow to the single factor of involved floor
a and which does not account for other factors which are known to affect
er usage.

Better links between researchers and research users. Another means for ıproving disaster planning would be to hold periodic workshops and con-ːrences between policy makers, researchers, and users of research. These ıould be held both before research agendas are developed, to improve agenda-ːtting, and after studies have been undertaken, to disseminate knowledge ıd appraise the utility of research products.

onflagration Analysis Study

hort Description: This report covers a study committee of the American ssociation for the Advancement of Science to discuss among other issues he dynamics of disasters as a problem set that can be appropriately invesigated the process of scientific engineering, and professional communities n a workshop framework. In one specific instance it was recommended the onflagration type planning could be improved by holding periodic workhops and conferences between policy makers, researchers, and users of esearch. Relative to this issue, the conference participants focused on he four areas of planning-research discussed in the summary.

itle: Fire Safety and Disaster Preparedness

uthor: Staff, American Association for the Advancement of Science

rganization: American Association for the Advancement of Science

ibliographical Data: Intergovernmental Research and Development Project, Office of Public Sector Programs, American Association for the Advancement of Science. Fire Safety and Disaster Preparedness. Washington, D.C.: American Association for the Advancement of Science, March 14-16, 1979.

ummary:

The working group discussed the status of research and recommendation or research for each of four phases in disaster planning: mitigation, prearation, response, and recovery. The research needs in each of these phases ere organized into five areas: information, coordination, regulation, esource mobilization, and evaluation. The group's five major recommendations re outlined below.

Technology transfer. There is a need for research on ways of transfering both existing and new knowledge to the general public, to state and ocal officials, and to the research and development community. The estabishment of a national clearinghouse on disaster preparedness, response, and ecovery is one means by which technology transfer could be accomplished. n intensive assessment should be made of the value of establishing such clearinghouse.

Evaluation research. As in other areas of federally-sponsored research, valuation research should be undertaken in the disaster area. An appropriate ortion, say ten percent, of federal funds granted should be designated for valuation of programs in all four disaster phases.

Policy research. There is a considerable need for policy research on ll four disaster phases. Although research is needed on all pre- and postisaster phases, we recommend that policy research be undertaken particularly n mitigation and recovery efforts, two badly neglected areas. Legislative nd regulatory conflicts, gaps, and duplications indicate the need for intensive and detailed studies of existing laws, statutes, ordinances, and olicies to identify specific changes that are needed to make these various egulations compatible.

such a unit, the control possible in simulating ignition characteristics of single and multiple units makes the simulator attractive as a means of modeling mass fires.

5. As disclosed by the study of the 1922 astoria, Oregon conflagration, very few conflagrations have occurred in which adequate documentation of pertinent data was accomplished. It is believed, however, that sufficient data can be obtained from such actual mass fires to effectively evaluate mass fire models.

Conflagration Analysis Study

Short Description: The objective of this program was to establish the potentiality of a model technique as a means of studying the propagation of fires initiated by nuclear attack. The program involved two requirements. First, to determine if a physical representation of a city selected for study could be made. Secondly, to determine if there could be developed a technique for predicting fire spread using limited data: a map, the weather pattern, the characteristics of terrain, the type of building construction and the probable effectiveness of local fire defenses. It is concluded that the theoretical and experimental development of fire models leads to the conclusion that information and unit techniques previously available are not well suited to the prediction of fire spread or the development of mass fires.

Title: The Use of Models for the Investigation of Fire Spread

Author: John E. Ambrose, Lester A. Eggleston, and Calvin H. Yuill

Organization: Southwest Research Institute

Bibliographical Data: John E. Ambrose, Lester A. Eggleston and Calvin H. Yuill. The Use of Models for the Investigation of Fire Spread. San Antonio (TX): Southwest Research Institute, DASA Project No. 12.024, 1965.

Summary:

The study authors conclude that the feasibility of an electronic fire simulator appears to be well established. Circuitry has been developed, the requirements for both input and output devices are now known, and the development of a module useful in mass fire studies is now dependent upon miniaturization, calibration, and fitting of the characteristics of the module to typical experiences in unit and mass building fires. This initial work leads to a set of conclusions or may be hypothesis for future work as follows.

1. The most promising method is the simplified scaling of typical buildings to the size required, using selected materials. This technique has not been utilized at the small scale suggested in this report nor has it been used in the study of mass fires.

2. It is conceivable that equations could be written, assuming many probabilities, by means of which existing data could be extrapolated both up and down as the basis for constructing a physical model of the scale reduction implied. Considerable supporting test work would be required to engender confidence in this approach.

3. There is a good possibility that mass fire spread can be modeled on the basis of interacting unit fires. Experimental work on progessively complicated models would be the most promising approach.

4. The feasibility of an electronic fire simulator has been demonstrated on a limited basis. Although fire brand effects and the volume increase in gases resulting from combustion do not now appear to be reproducible with

effective in protecting against exposure fires while specially designed exposure water spray systems are highly effective in the interruption of fire spread. The record appears to indicate that an exposing fire entering a sprinklered building will have a tendency to over tax the water system making the sprinklered building system ineffective in controlling the "entering fire." Therefore, there is no quantitative credit given for internal sprinkler protection in assessing the variables for block rating analysis.

However, it does appear important to carefully consider special designed exposure protection in assessing fire spread from one building to another. Exterior sprinklers are considered in the same class as solid walls as effective means of controlling exposure problems. A damper on the potential measure of sprinkler exposure protection is the hard fact that there is little evidence of this fire protection equipment in the "real world." This type of exposure protection has very limited application.

Institute of Technology Research Institute under the direction of Labes, Vodvarka, Salzberg (et al). In relation to manpower functions four variables were analyzed in 73 fires in Chicago, Illinois.

Fire damage area was selected as the primary or dependent variable while the interviening or independent variable consists of (1) water application rate in gallons per minute, (2) water application as a density function, (3) fire control time, and (4) Manhours expended. The study concludes that after a developing fire reaches a threshold level of approximately 1,200 square feet, manpower utilization has an inverse relationship the developing fire. Water application rate is found to have a similar relationship.

It is important to note that the researchers did not find a correlation between personnel used on practice fires and simulated fires and real world fires. More personnel are used on real fires of a given size than on training fires of the same size.

K. Effectiveness of Internal Protection Systems

Internal protection systems for structures have long been considered significant deterents to fire development. The internal protection system for most occupancies is considered to be automatic sprinkler protection. Other agent systems such as Halon, High Expansion Foam, Dry Chemical, and Carbon Dioxide are usually limited to specific hazards areas in highly protected risks. The concern then becomes one of assessing the potential impact of automatic sprinklers in the development of the mass fire phenomena.

The initial literature search does not provide significant insight on this matter. A study by Gomberg and the Insurance Services Office Fire Suppression Rating Schedule on Water Supply does give a general persepctive on sprinkler protection for multiple structural fires in a single complex. Essentially, internal sprinkler are not considered

I. Weather Analysis

One central theme stands out in the conflagration problem literature. Weather conditions are one of the most significant factors in the consideration of mass fire development and conflagration type fires. Weather appears to dominate the fire scenario. Yet, there is only a meger amount of quantitative information on the specific analysis of the weather phenomena in measuring conflagration potential. Weather is an elusive factor that has not been carefully quanified in the fire spread equation.

The important work on weather and fire appears to be confined to natural cover fuel fires. The forestry service, as reported by Roberts, and their allied organizations have done extensive investigations into weather and fire in relation to both forests and the wild land fire problem. Weather there is any correlation between the weather indices of the natural cover fire problem and the structural fire problem is not revealed in the literature examined todate.

Because of the overriding importance of weather and fire development in structures and in the mass fire problem, careful donsideration will be given in the Phase II review of literature to specifically focus on this issue. It appears very important to include a quantitative measure on weather conditions in the analysis method of mass fire and conflagration potential. The obvious difficulty is to operationally define what this quantitative measure should be in relation to the other analytical variables.

J. Fire Suppression Manning Levels for Large Scale Fires

Only one set of research has been identified at this time that relates specifically to the relationship between fire suppression manning levels and large scale fires. This research has been conducted at the Illinois

conflagration potential. Today, the Insurance Services Office criteria for "Needed Fire Flow" is more of a reflection on the single building fire and the relationship of that fire to exposure problems.

The analysis methods used for determining fire flow parallel in many respects the block rating methodology used in the Gage-Babcock conflagration Analysis. In the ISO method the variables of ground floor area, height, construction coefficients, and occupancy factors are used to determine a base fire flow rate for a structure without exposures. The "building complex" needed fire flow is based on an extensive consideration of exposure factors including wall characteristics, wall dimensions, and wall separations. It appears possible to directly cross correlate these variables with the same variable structure presented in the Gage-Babcock model.

Ball and Pietrazak report on a computer simulation model to estimate water application effectiveness in suppressing compartment fires. The model proposes several situation desriptors that are relevant to the compartment including: floor area, wall or perimeter factors, modular configurations, fuel geometry, and effectiveness of heat of combustion. Using these parameters, the model computes a water delivery rate, total water used, and time to control (not suppresss the fire). The methodology appears useful for examining the relative impact of the selected variables in computing the fire flow requirement. It is also important to note that this methodology is currently being validated in a study at the National Bureau of Standards. This study will monitor the findings during the period of the conflagration study to determine any potential applications.

It appears important to conduct a comparative analysis between the fire flow measurement techniques and the block rating techniques used in the conflagration analysis to determine if any correlation exists.

literature search for evaluating the exposure problem.

The understanding of the phenomena which controls fire development along vertical combustible surfaces represents an important aspect of the exposure problem. For the case of exposing walls, recent work by Tammanini, Butler, and Quinteri, has practical interest for the conflagration study. The interesting work involves walls which are sufficiently large to yield a turbulent flame where radiation controls the heat feedback to the surface.

Quantitatively, one can expect that, if the walls are sufficiently far apart, the interaction is minimal and the rate of burning approaches that of the single wall case. As the spacing between the walls is reduced, the following effects are reported to gradually alter the physical picture: (1) an increasing fraction of the radiation from the flame and from the hot fuel surface, otherwise lost to the surroundings reaches the wall; (2) the scale of the turbulent eddies is reduced by the presence of the additional solid boundary (the other wall); and (3) the flow of oxygen available for combustion in the gap is reduced. It is concluded that maximum expected burning rate corresponds to a wall spacing about equal to 20% of the wall height.

H. Fire Flow Analysis

For over seventy years the insurance industry has used "required water supply" as a measure of structural fire risk potential. Alternatively, water flow rates for a building or a building complex can be used as a quantitative measure of anticipated severity. Traditionally, water supply requirements promulgated under the Grading Schedule for Municiapl Fire Protection has reflected on area fire flow requirements as a function of

on this issue will be reported in the primary study document.

G. Radiation Measurement and Exposure Analysis

There is no area in the literature search that has received more attention and investigation concerning the fire growth phenomena in structures than the radiance factor in fire growth analysis. There are few authors that have escaped examining this phenomena. Radiation analysis between fuel interfaces, compartments and separate structures is a complex problem. The theories on this matter appear quite divergent. Yet, the significance of this parameter to mass fire analysis is critical to the overall creditability of the analysis technique.

The more important studies include the work of Berlin, Butler, Eggleston, the Insurance Services Office, Lee, McGuire, Miller, Takata, Thomas, and Vodvarka. From a review of the anotated bibliography, it may be concluded that this is one of the most complex issues in the determination equation of fire spread. Radiation flux has to be a prime analytical consideration in the evaluation of exposure conditions. To limit the literature to practical considerations, only those dimensions that appear to be relevant to post flashover senarios will be considered in the block rating analysis.

At least ten separate equations have been identified for determining the radiation effect of a fire on an exposure. Except for a limited amount of work by Butler, there appears to be little analytical comparison between the identified methodologies. A case study of the several methodologies is important to the refinement of the block analysis method used in the conflagration analysis. This will be accomplished in the study document that directly addresses the quantitative measures presented in the identified

Insurance Services Office and reported on by Reigal, there appears to be no alternative American approach to risk assessment beyond the foundations of the insurance industry. This observation rem 'ned constant as the study progressed.

F. Fire Load Measurement

No single variable in structural fire development analysis appears as important as "fire load measurement." This concept refers to the amount of fuel available in the structure under consideration; it is measured on a square foot basis in units of pounds. In other words the fire load or fuel load is an expression of the amount of burnable material per square foot of the occupied area. The intensity or the severity of fire is directly considered in relation to the fire load measure.

Literally all of the attached references in the Bibliography pertaining to the conflagration analysis study reflect on fire load measurement in a direct or indirect manner.

Fire intensity in a structure has to be a function of the fuel load consideration. This premise is supported by at least the following authors and researchers: Ball, Pietrazak, Berlin, Butler, Coward, Eggleston, Fang, Foster, Insurance Services Office, Kohlhammer, Lee, Lie, McGuire, Quintiere, Riegal, Salzberg, Takata, Thomas, and Vodvarka. Furthermore, there appears to be considerable agreement on the potential measure of fuel load as reflected in the National Fire Protection Association publications.

The literature further indicates that fuel load is predominately related to occupancy. Therefore, the current conflagration methodology for block rating analysis should consider the updated information on occupancy fuel load as it reflects on fire development, especially in the development of the mass fire phenomena. The analytical perspectives

(3) inadequate water supply, (4) adverse weather conditions including low humidity, excessive winds, and extreme temperatures (high and low) and, (5) marginal or inadequate public protection forces. After this general categorization comes the more difinitive analysis and variable relationships.

The insurance interests represen ted by the National Board of Fire Underwriters, and more currently by the Insurance Services Office, has concentrated on water supply as the prime factor associated with the measurement of fire control potential for conflagrations. In other words fire control potential is measured in terms of required fire flow on an area base. It is presumed that the higher the fire flow the greater the conflagration potential.

The original work by Gage-Babcock and the supplemental work by the same organization, is the only documented approach to conflagration analysis todate as reported in the standard literature references. This simply means that there has been no real substantive work in the specific area of conflagration analysis since the late 1960's. The current study in the area should be a refinement on the initial work and make this work relevant to the 1980's.

E. Risk Assessment

This topic may be very important to the quantitative analysis for measuring fire frequency and severity. Much has been written on the subject of fire risk analysis; a considerable portion of the literature on this subjectrelates to insurance measures of "risk." The work of Reigal, Koelhammer and the Insurance Services Office appear to be the significant works in this area. Risk assessment essentially involves the variables identified in Table 1. Except for the rating schedule developed by the

The function of the simulation which we have developed, called the Fire Demand (FD) Model for short, is shown schematically in Figure 2. The FD Model is designed to relate the suppression effort via a simulation of the fire character to the suppression results. Fire character is determined by building and fuel parameters. This approach was developed to meet the objectives of a project for NSF/RANN of identifying deficiencies in mobile fire suppression apparatus, identifying research areas of high potential, and of eventual perfection of equipment specifications. The fully involved (post-flashover), single compartment fire was chosen as the fundamental model not only because it represents a stressful fire suppression situation, but also because previous investigators(1) have successfully modeled this fire in its freely burning phase without suppression. Their methods, which we follow, calculate the fire development in terms of lumped parameters describing the energy and mass balance of the compartment as a whole. The FD model adds to this work the effect of suppression efforts with applied water. Figure 2 shows in general terms the principal inputs, outputs, and operating parameters of the FD model and suggests the relation of fire service operations to the physical inputs required to characterize the suppression effort.

The level of detail of the model is determined by its practical objectives and the requirements of simplicity and computability. An appreciation of this level is provided by the following listing of model parameters.

SITUATION DESCRIPTORS (INPUT)

COMPARTMENT

- Area of Ventilation Opening
- Vertical Height of Ventilation Opening
- Floor Area
- Compartment Height
- Wall/Ceiling Area
- Wall Thickness
- Wall Type (heat capacity and conductivity)

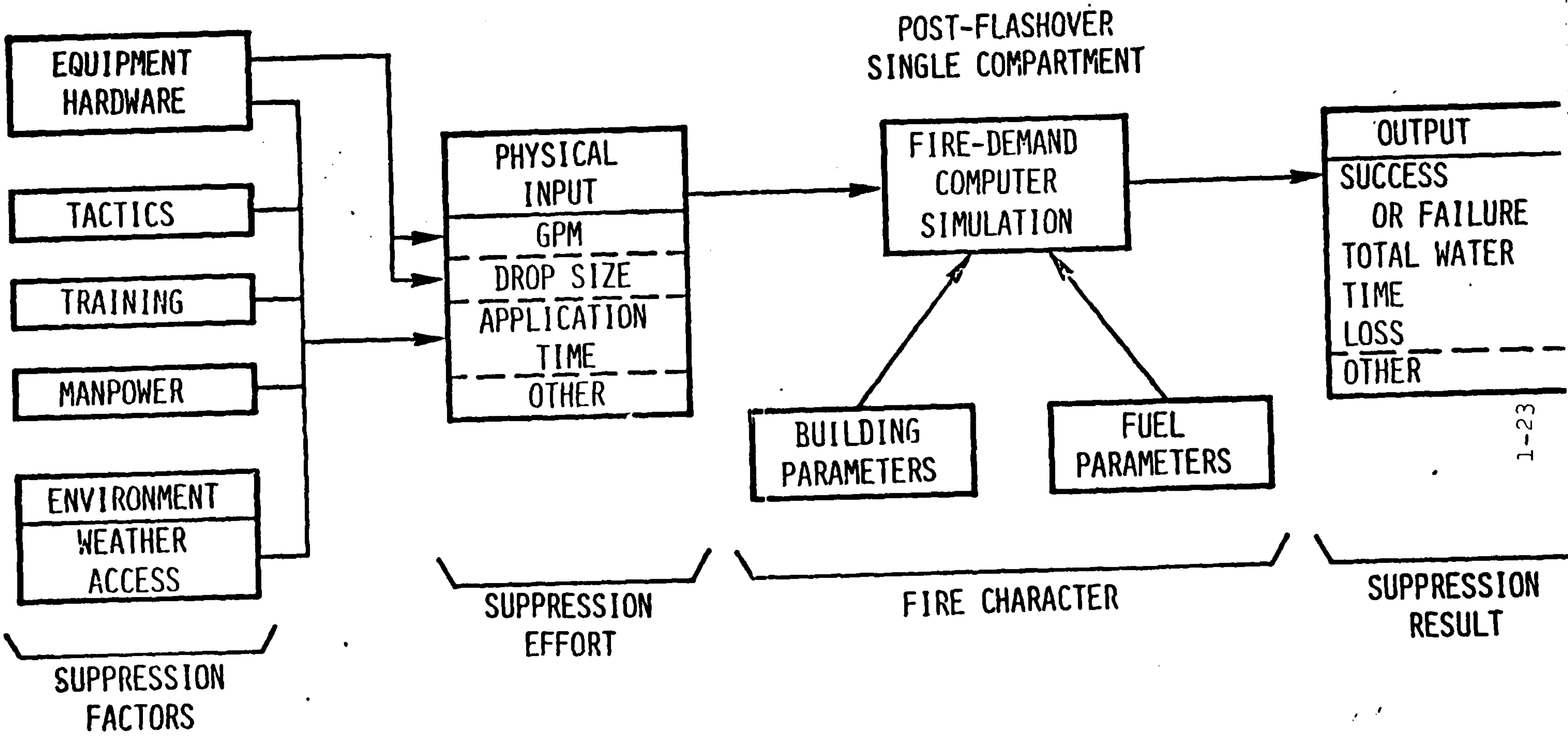
FUEL

- Fuel Load (weight/unit floor area)
- Fuel Surface Area
- Fuel Surface Exposed to Water Impact
- Effective Heat of Combustion

WATER APPLICATION

- Water Delivery Rate
- Time of Water Application (after flashover)
- Cone Angle of Hose Stream
- Sweep Time of Compartment Coverage
- Volume Median Drop Diameter of Water
  (Determines an assumed Rosin-Rammler distribution of drop sizes in hose stream)

SIMULATION APPLICATION



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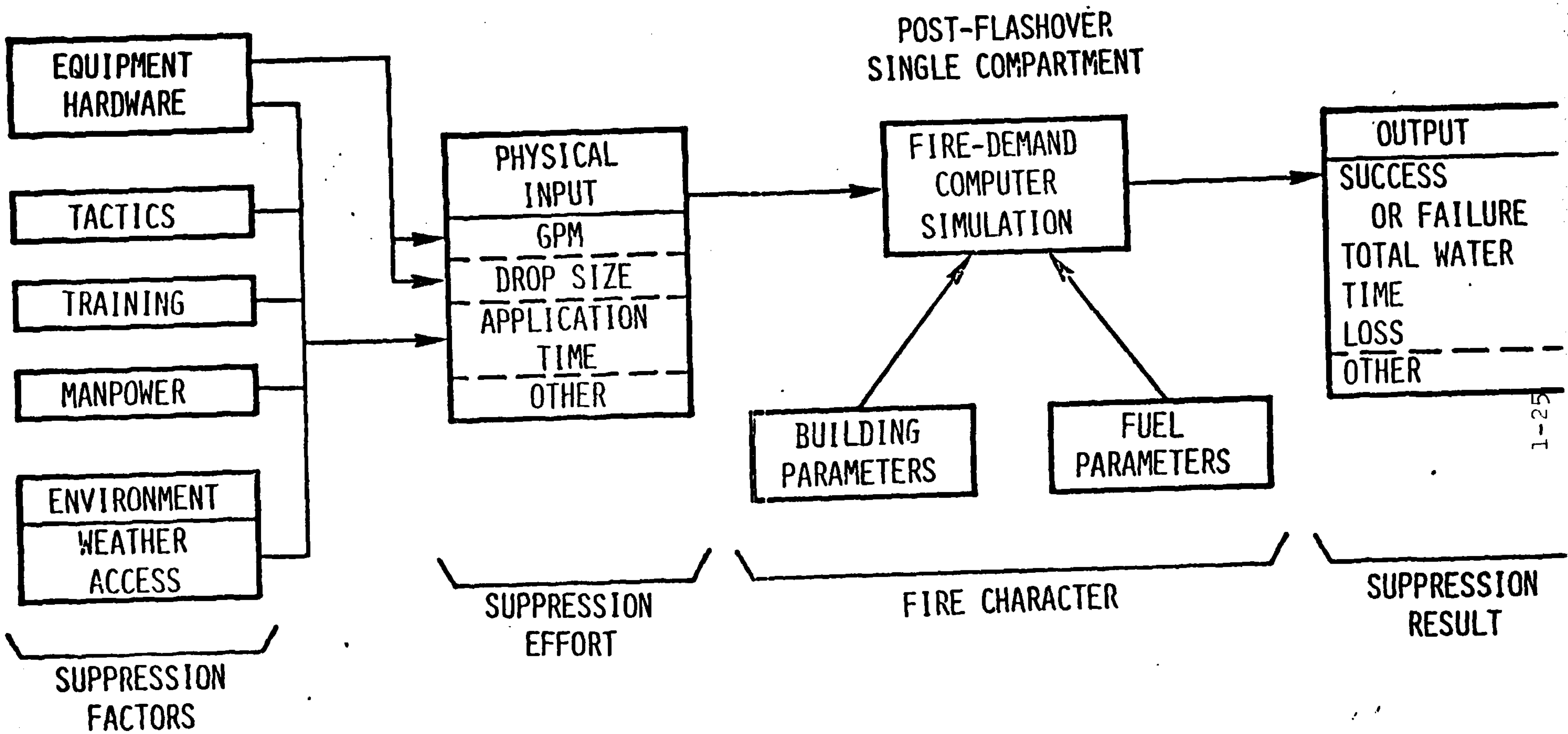


Figure 2.

RESULTS (OUTPUT)

Knockdown/Failure
Total Water Used
Total Water Vaporized
Total Water Unvaporized
Time to Knockdown (if achieved)

SECONDARY

Fuel Remaining
Temperature History of Compartment Gas
Temperature History of Wall/Ceiling Surface
Retained Heat in Structure

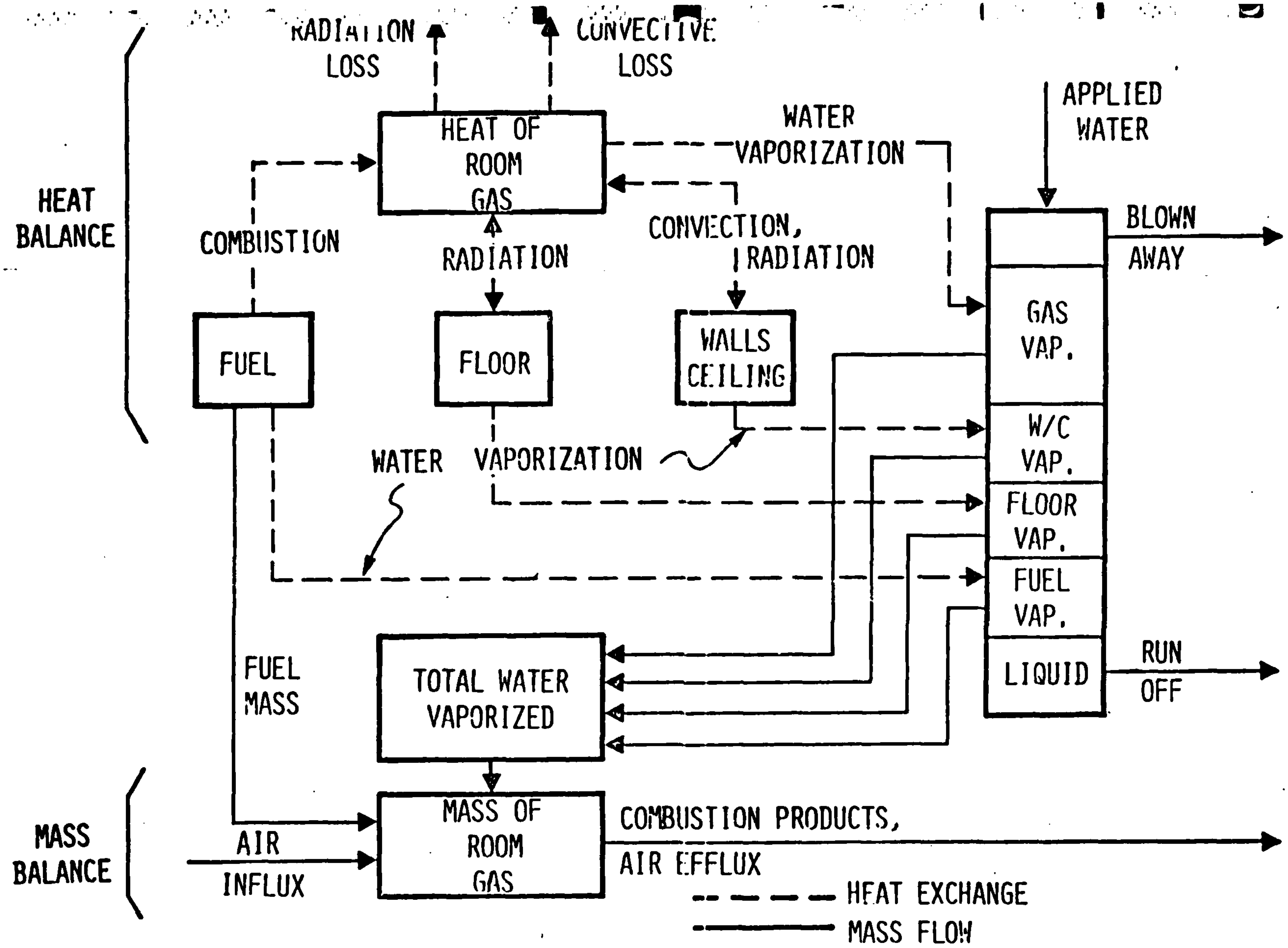
Figure 3 provides an overview of the physical effects and interactions which are incorporated in the model. Starting from assumed conditions at flashover the model advances the fire in a succession of time steps. Alteration of conditions with time is determined by preservation of a balance of heat transfer rates to the gas of the room and by preservation of a mass balance of matter entering and leaving the compartment. In Figure 3 heat exchange is indicated by dotted lines and mass flow is indicated by solid lines.

In Figure 11 the predictions of the FD simulation are compared with some experimental results obtained by Salzberg, Vodvarka, and Maatman(4). These experiments are essentially the only applicable data we have found which give water usage for suppression of compartment fires by mobile hose-nozzle systems as opposed to fixed sprinkler systems. These data do not record the values of several parameters to which model results are sensitive so we have chosen reasonable values for the simulation. For example, we assume a volume median drop diameter of 0.3 mm which is perhaps typical of the spray nozzles used in the experiments.

The scatter of the experimental data is shown by the heavy dots and the curve is drawn through their average. The experiments found that a water application rate less than 6.6 gpm did not control the fire. The minimum application rate required for knockdown in the simulation is 9.0 gpm. In comparison with these experiments the FD model predicts are reasonable but somewhat conservative, an expected result deliverately built into the model. The too sharp rise of the total water requirements at high application rates shown by the simulation is a descrepancy which indicates that the model underestimates the rate of interior surface cooling.

CONCLUSION

Development of the FD model is continuing and quantitative calibration by experimental testing is planned. The results to date, however, are sufficient to establish the utility of this modeling approach as a versatile tool for quantifying effectiveness of water as used by fire services in the suppression of compartment fires.



INTERACTIONS OF FIRE DEMAND MODEL

Figure 3.

COMPARISON WITH EXPERIMENTS

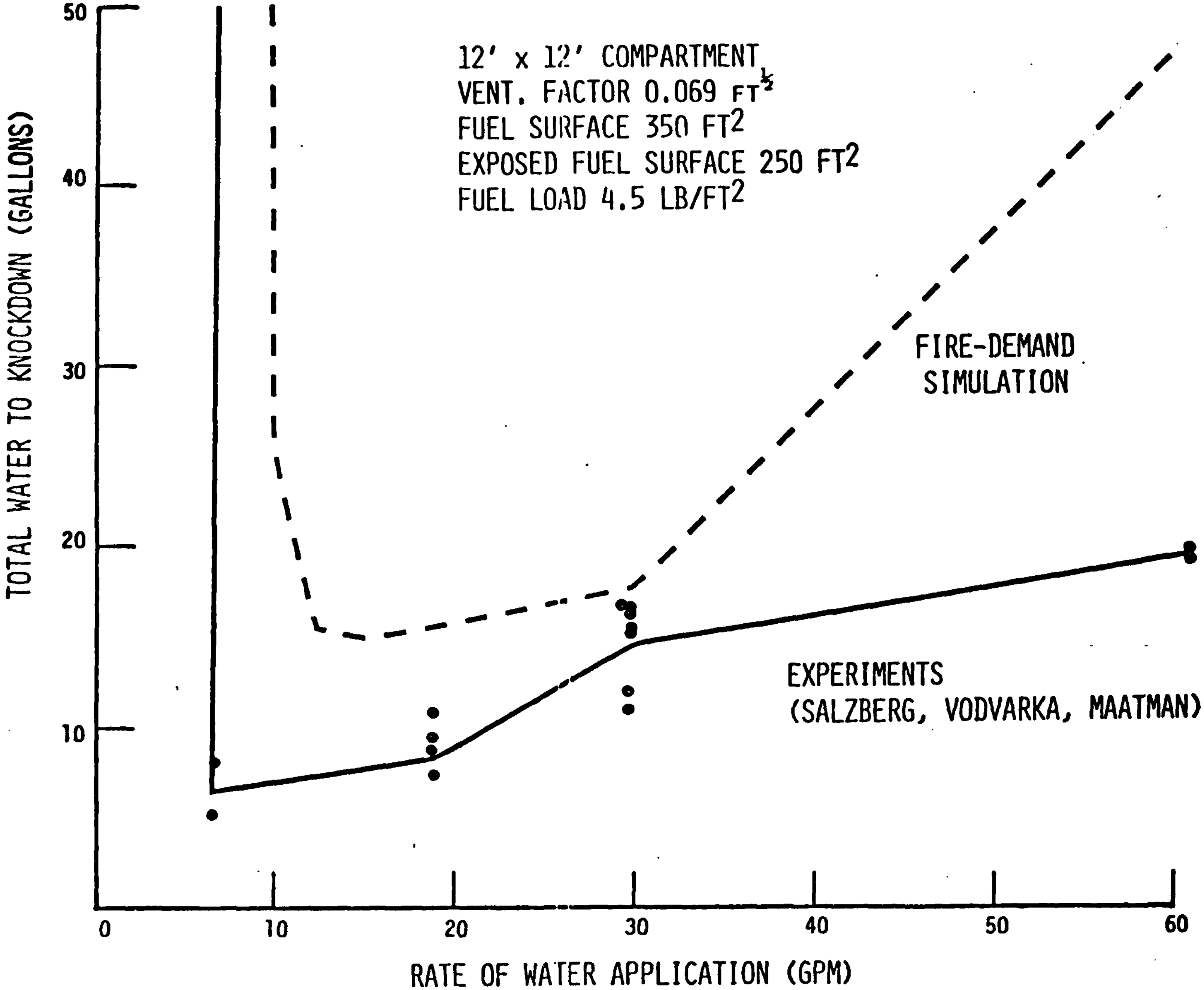


Figure 1[illegible]

Conflagration Analysis Study

Short Description: Many injuries associated with fire situations are due either directly or indirectly to the products of combustion rather than to structural failure. In an attempt to determine the effects of building design and contents on the hazards of fire, the N.F.P.A. has developed a state-transition computer simulation of fire development. This model will provide a tool for evaluating the temporal and spatial impact of fire development in a proposed existing facility.

Title: A Simulation Model of Fire Hazards

Author: Geoffrey N. Berlin

Organization: National Fire Protection Association

Bibliographical Data: Geoffrey N. Berlin, "A Simulation Model of Fire Hazards," A Paper Presented at the Joint National ORSA/TIMS Meeting, Peachtree Plaza Hotel, Atlanta, Georgia, November 7-9, 1977. (Project funded by the Department of Housing and Urban Development.

Summary:

The computer simulation describes the temporal and spatial characteristics of fire development along with the combustion products of fire development for a specific facility design. Fire development is described in terms of a finite number of states or "realms." The conditsion defining each realm reflect relatively distinct phases in the hazards of fire as well as the associated development and spread of the combustion products. Each realm is defined by either or both heat release rate and upper room air temperature. While specific conditions for these parameters are not always consistent, there is sufficient commonality to justify their use in defining a particular realm. This is especially true when considering the relative hazard represented by each realm and the extreme variability of any fire characteristic.

Figure 1 presents currently used definitions for each realm. Higher order realms are used to represent significant fire growth both in severity and spatially. As indicated by the realm definitions, extension of the fire is often considered at least as important as the fire development within the room of origin. Once a particular realm is reached, the means of reaching that realm is no longer considered. Furthermore, fire development does not necessarily involve passing through all consecutive realms since transitions can represent both fire recession and explosions. In addition, some rapidly growing fires can in effect pass through a particular realm so quickly that it is inappropriate to isolate the transition.

While this simulation is not particularly complex, it does have considerable value as a reach and decision making tool. It provides a general framework for unifying the results of single item and full scale fire tests in addition to other computer modeling efforts. Furthermore, the model is an essential tool for the systematic examination of the physical processes of fire development, alternative designs, and detection equipment and their

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implications for imporved fire safety. These few examples provide ample evidence of the importance in considering in detail the possible paths for the spread of the combustion products.

Figure 1

REALM CONDITIONS

FOR SINGLE FAMILY DWELLING

REALM	CONDITION
Realm 1	No Fire
Realm 2	Ignition (including smoldering) has occurred in the room of origin, but heat release rate does not exceed 2 kJ/s.
Realm 3	Heat release rate in the room of origin is between 2 kJ/s and 50 kJ/s, or average upper room temperature is less than 150°C.
Realm 4	Average upper room temperature in the room of origin is between 150°C and 400°C. This realm includes secondary ignitions beyond the room of origin with heat release of less than 2kJ/s.
Realm 5	Average upper room temperature in the room of origin is greater than 400°C. This realm includes secondary ignitions beyond the room of origin with heat release of less than 2 kJ/s.
Realm 6	Involvement beyond room of origin of between 2 and 50 kJ/s. This means that the fire outside the room of origin has reached its own Realm 3 condition.
Realm 7	Invovlement beyond room of origin greater than 50 kJ/s, or average upper room temperature is greater than 150°C. This means that the fire beyond the room of origin has reached its own Realm 4 condition.

---

kJ/s = kilojoule per second = kilowatt (kW)

$J/(cm^2.s)$ = heat flux = joule per square centimetre - second = watt per square centimetre.

J = joule   W = watt   cm = centimetre   s = second

Conflagration Analysis Study

Short Description: A major research effort was started in 1970 to evaluate experimentally the dynamic behavior of structural fires in the context of civil defense implications following nuclear attack. This report describes the accomplishments of the first year's effort which include (1) experimental measurements of the dynamic characteristics of fires in one-story wooden buildings, (2) methods used for correlating and interpreting the resulting data, and (3) attempts at reduced-scale modeling of such fires.

Title: Measurements of the Dynamics of Structural Fires

Author: C. P. Butler

Organization: Standford Research Institute

Bibliographical Data: C. P. Butler, Measurements of the Dynamics of Structural Fires. Menlo Park, California: Standford Research Institute, 1970 (Contract DAHc20-70-0219)

Summary:

The report indicates that for the most part, tests were conducted in single, uncollapsed structures in which fires were started in a single room at one end of the structure. In one full-scale test, a structure was partically collapsed to simulate moderate blast damage, and in another series, two long, parallel structures were burned simultaneously to observe effects of interactions.

Measurements included weight-loss rates, energy-release rates, radiant fluxes, rates of fire propagation through structures, fire-induced inflow winds, CO and CO_2 production, oxygen depletion, optical attenuation by smoke, and ignition of nearby fuel speciments. In spite of substantial differences in the conditions of test, notably those due to weather variables, many consistencies in fire behavior characteristics and associated environmental factors were found.

Radiometric measurements were shown to be a practical means for characterizing the burning rate of test fires in such structures. The pulse of radiant flux with time as measured at a distance in a suitably chosen direction correlates well with rate of weight loss as a function of time. Maximum burning rates in full-scale barracks sections occurred from 16 to 26 min after ignition, with corresponding energy release rates of about 2×10^9 to 4×10^9 cal min^{-1}. Fire appeared to spread through these buildings in a more nearly linear than exponential fashion. Rates of spread were estimated to be 12 ft min^{-1}. To the extent that the data can be represented by exponential growth of volume involved in fire, the doubling time was estimated to be only about 2.5 min. Whichever method is used to express the rate of spread, the values clearly reflect

the highly combustible construction of the test buildings. The dynamic characteristics in partially collapsed structures appear to be substantially different than those of their undamaged counterparts.

Carbon monoxide was found to be the major life hazard insofar as atmospheric composition is concerned. Measurements of CO concentration were translated into escape restraint time ranging from as short as 5 minutes in open rooms to no more than 21 minute in a simulated subgrade shelter.

Measured inflow winds were quite modest for all tests. Velocities ranged from 2 to 8 mph at a height of 6 ft above grade and a distance of 10 ft from the outside walls.

The relatively unsophisticated models employed in the study to date exhibit dynamic fire characteristics that are encouragingly similar to those of the full-scale counterparts. The development of small-scale models, however, must be regarded as preliminary.

flagration Analysis Study

rt Description: This study presents a simulation method that may be d to combine the distributions for fire load, room dimensions and window a, which were obtained from independent sources. The model concept is ed on studies that demonstrate that in a given compartment or room, fire erity varies with the quantity of combustible material (fire load), the a of ventilation, and the dimensions of the compartment.

le: A Simulation Method for Estimating the Distribution of Fire Severities in Office Rooms.

hor: Sara K. D. Coward

anization: Fire Research Station, Borehamwood

liographical Note: Sara K. D. Coward, B Sc., "A Simulation Method for Estimating the Distribution of Fire Severities in Office Rooms." Borehamwood, England: Building Research Establishment, Fire Research Station, 1975.

mary:

Each distribution to be used in the simulation was built up by a udo-random number series independent of all other series. The program erated a model population of office rooms, room by room, so that the al population had exactly the same distributions for different factors those obtained from the original surveys. The process was performed each room as follows, until a population of 20,000 had been generated:

Selection of room area

) Selection of room shape (depth:width ratio). The width and depth of the room could then be calculated since

width = Area/depth:width ratio

$$\text{and depth} = \frac{\text{area}}{\text{width}}$$

) The glazing percentage. Since the glazing percentage frequency distributions varied between rooms of different depth (Table 2) selection of the distribution to be used was made according to the depth of the room, using data from Table 2.

ill height of 3ft 6in and a room height of 10ft were assumed. The height the windows was therefore taken as 6ft 6in. Since the glazing percentage defined as the proportion of the entire window wall glazed above sill el:

= 6.5 x room width x plazing percentage for rooms with one window wall;

6.5 room width x glazing percentage for rooms with two opposite window ls;

4. Window shading

    a) Usage

    b) Are window coverings an ignition source

5. Window Transmissivity

6. Exposure of Interior through Window Aperature

    a) Ignition Plane

    b) Sill Height

    c) Window size

    d) Window width/height

7. Definition of Fuel Array

8. Number of Fuel Arrays

9. Size of Room

10. Critical Ignition Energy

11. Multiple Ignitions

12. Probability of Flashover

The sensitivity of these issues to conflagration analysis needs to be
, explored and numerically assessed in relation to the predictive model
:ture.

agration Analysis Study

Description: This report details the research and analysis supporting mendations on selection among four models of the ignition potential clear attacks on urban areas. The models studied were those developed T Research Institute, Systems Science, Inc., URS Systems Corporation, he U.S. Naval Applied Science Laboratory.

: Analysis of Four Models of the Nuclear-Caused Ignitions arly Fires in Urban Areas

rs: R. Keith Miller, Milton E. Jenkins, and James A. Keller

ization: The Dikewood Corporation

ographical Data: R. K. Miller, M. E. Jenkins, and J. A. Keller, Analysis of Four Models of the Nuclear-Caused Ignitions and Early Fires in Urban Areas: Albuquerque, New Mexico, The Dikewood Corporation, (Contract No. DAHC20-70-C-0222 -- Work Unit No. 2619B), 1970.

ary:

Factors investigated include the accuracy of the various assumptions and ytical techniques employed by the models, the sensitivity of the models ariations in the input parameters, and the adaptability of the models ncreased knowledge of fire phenomenology. Under the criteria used, the l Applied Science Laboratory model is the best of the four. However, it eported that both improvement in the data base and modification of the l would be required before its predictions would be compatible with those xisting fire spread models. Prior to these improvements, it is suggested the IITRI model be employed, with several suggested modifications that d increase its accuracy.

The parameters used for the comparative analysis of the referenced models ar important to the conflagration analysis study. These parameters with implications are stated as follows:

1. Free-field thermal energy

2. Building faces exposed

3. Shielding by:

   a) Terrain

   b) Trees

   c) Adjacent buildings

   d) Elevation angle

ɔnflagration Analysis Study

ıort Description: It has been implied that spacial separations based on :ak radiation levels will prevent ignition by radiation, indefinitely. ıe specified distances, however, exceed practical limits. Separations ılculated to prevent ignition by radiation long enough for fire extinguishing ɔerations to be initiated have been tabulated. The author explains how the ıbles were derived and discusses problems that may be encountered in thier ıe.

.tle: Fire and the Spatial Separation of Buildings

ıthor: J. H. McGuire

:ganization: National Research Council (Canada)

.bliographical Data: J. H. McGuire, "Fire and the Spatial Separation of ıildings," Fire Technology, Vol. 1, No. 4, November 1965.

ımmary:

The radiation levels to be expected from burning buildings were investigated ı the course of a program of full-scale burns known as the St. Lawrence Burns ırried out by the Division of Building Research, National Research Council, ıring the winter of 1958. The following were the principal findings:

1. The nature of exterior cladding - brick or clapboard - did not noticeably influence radiation levels.

2. Peak radiation levels at some distance from the buildings coincided with those that would result if window openings, at an appropriate hypothetical temperature, were taken to be the only sources of radiation.

3. Peak radiation levels from buildings with highly flammable linings were twice those from buildings with noncombustible linings.

4. Radiation levels were affected by wind direction, those on the leeward side of a building being, in general, much greater than those on the windward side.

McGuire reexamines this evidence. He noticed that although the fires ıd been arranged to develop very rpaidly, radiation levels did not exceed ıe-fifth of the peak values listed, i.e. 40 and 20 cal/sq.cm/sec until at :ast 16 min. had elapsed. As fire fighting is in progress at this stage ɔr the great majority of fires, it is possible that spatial separation ɔuld perform adequately if it merely gave protection against the spread of .re during this period. In many cases, spatial separation claculated on ıis basis would, in fact, protect a building indefinitely, from the ıdiation levels previously discussed are maximum and would not always prevail.

Conflagration Analysis Study

Short Description: The Book deals with various aspects of protection of buildings against spread of fire and collapse. Research in this field has advanced rapidly in the last two decades, and current knowledge and applications of research results to practice are described.

Title: Fire and Buildings

Author: T. T. Lie

Organization: National Research Council of Canada

Bibliographical Data: T. T. Lie, Fire and Buildings. London: Applied

Summary:

This book discusses the control of fire in buildings by compartmentation, the use of fire-resisting structures, and the use of materials with a low contribution to fire growth. It also deals with the performance of some fire safety elements, such as roof vents, and curtains to prevent spread of heat and smoke. Methods are given for estimating the expected fire severity in buildings and the requisite protection of structures to resist fire. Subjects related to fire control, such as radiation from one building to another, the hazard of flames from windows and the removal of heat and smoke by roof venting, are considered.

Of special importance to the conflagration analysis study is the descriptive material given on the development process of fire and the estimation of the expected temperature and duration of fires in buildings. Also of importance are the methods discussed for determining the length of flames from windows, the safe position of objects exposed to radiation from burning buildings, and the principles of roof venting to remove heat and smoke.

It is also important to note that Lie gives particular emphasis to prevention methods for the spread of fire by compartmentation of a building with fire resisting constructions, and consideration is given to experimental and theoretical methods of determining the fire resistance of structural elements such as floors, walls, columns and beams.

Attention is also paid to economic aspects of fire. An increasingly important subject is the determination of appropriate fire-resistance requirements for buildings. A rational method based on balancing the cost of providing fire protection against the benefits is discussed. The points made need to be taken one step further to assess the impact of fire resistance modules for the limitation of fire spread in mass fire or conflagration situations.

Conflagration Analysis Study

Short Description: This paper notes that the criteria for making evaluative judgements about the reinforcing or desrupting tendencies of features of the physical envioronment are provided quantitatively where possible and qualitatively otherwise for the analysis of fire spread in buildings. The objective here is to provide the buildings designer with the available knowledge about the relationship between fire and the environment in order to increase his/her confidence in making what at times will be soft judgements. The same concepts appear valid for the reverse process of analyzing existing conditions.

Title: Learning From Fire: A Fire Protection Primer for Architects.

Author: Lars Lerup

Organization: National Fire Prevention and Control Administration

Bibliographical Data: Lars Lerup, David Cronrath and John Koh Chiang Liu, Learning From Fire: A Fire Protection Primer for Architects. Berkeley, (CA): Center for Environmen tal Design, 1977

Summary:

The following topical areas summarize the author's findings on fire safety design:

1. Ceiling Height: This criterion refers to the distance between a package of fuel and the ceiling. If the height is low the fire will cause the ceiling to increase in termperature. This increase in termperature is a precondition for flashover and therefore a low ceiling height will be considered to reinforce the tendency for the fire to continue to develop.

2. Room Volume: If the volume of a room is large, it could be a factor in disrupting the tendency for flashover to occur. Therefore, as the volume of a room increases, the tendency toward distruption of fire development also increases.

3. A compartment Fuel Load: Tests indicate that a compartment with 5 lbs/sq.ft. or less of room furnishing will have a tendency to disrupt the fire's continued development.

4. A compartment Fuel Distribution: If the fuels are arranged to make many discrete fuel packages, the tendecny for fire development is judged to be disrupted. On the other hand, if the fuels are closely packed together making one or two fuel packages in the space, the fire's development is tnen judged to be reinforced.

The above factors appear important to any discussion of fire development in structures.

Conflagration Analysis Study

Short Description: This paper is based on a fire safety factor classification system developed in Germany. The material was translated into English by the American Iron and Steel Institute in 1970. The variables computed for the determination of the industrial structures fire protection class are of importance to the measures of fire risk analysis.

Title: "Determination of the Fire Protection Class of Industrial Structures."

Author: W. Kohlhammer

Organization: German Journal of Fire Departments

Bibliographical Data: William Kohlhammer, "Determination of the Fire Protection Class of Industrial Structures." German Journal of Fire Departments. DIN 18330. June 1978

Summary:

The uniqueness of this paper is in the assessment and calculation of uniform fire load. The base line information is presented as follows:

Basic Calculation

The fire load - Q_r - in Mcal/m^2 is calculated:

a) not considering a recognized fire department

$$q_r = qB$$

b) for one story buildings

$$q_r = qBe$$

c) considering a recognized fire department:

$q_r = qBd$ or $q_r = qBed$ where:

q = fire load of the compartment in Mcal/m^2
B = an m evaluating and safety factor
a = area factor
e = reducing factor
m = evaluating factor
n = story factor
d = fire control factor

Based on the calculated fire load - q_r - the fire protection class is found in Section 5 of the report.

Occupancy Factor (O_i):

The factors below reflect the influence of the occupancy in the selected building on the Needed Fire Flow.

Occupancy Combustible Class	Factor (O_i)
C-1 non combustible	0.75
C-2 limited combustible	0.85
C-3 combustible	1.00
C-4 free burning	1.15
C-5 rapid burning	1.25

Calculation of Needed Fire Flow (NFF_i)

$$NFF_i = (C_i)(O_i)(X + P)_i$$

The relative weight of the variables identified in the fire flow methodology appear to be the essential same set of variables associated with the mass fire development process outlined in the original conflagration study. The association of variables are discussed in the primary study document.

Conflagration Analysis Study

Short Description: The Insurance Services Office method of computing Needed Fire Flow for a building or group of buildings evaluates many of the variables associated with structural risk analysis and fire spread between buildings. The analysis method is used in both the computation of fire flow for commercial risks and municipal gradings.

Title: Needed Fire Flow

Author: Insurance Services Office

Organization: Insurance Services Office

Bibliographical Data: Insurance Services Office. Fire Suppression Rating Schedule. New York, (NY): Insurance Services Office, July 1981.

Summary:

This item develops the Needed Fire Flow for selected locations throughout a given city which are used in the review of subsequent items in the Grading Schedule. The calculation of Needed Fire Flow (NFF) for a subject building in gallons per minute (gpm) considers the Construction (C_i), Occupancy (O_i), Exposure (X_i) and Communication (P_i), of each selected building, or fire division, as outlined below.

Construction Factor: That portion of the Needed Fire Flow attributed to the construction and area of the selected building is determined by the following formula:

$$C_i = 18F\,(A_i)^{0.5}$$

F = Coefficient related to the class construction

- = 1.5 for construction class 1 - frame
- = 1.0 for construction Class 2 - joisted masonry
- = 0.8 for construction class 3 - non combustible and construction class 4 - masonry non combustible
- = 0.6 for construction class 5 - modified fire resistive construction class 6 - fire resistive

A_i = Effective Area

The maximum value of C_i is limited by the following:

8,000 gpm for construction classes 1 and 2
6,000 gpm for construction classes 3, 4, 5, and 6
6,000 gpm for a 1 story building of any class of construction

The minimum value of C_i is 500 gpm. The calculated value of C_i is rounded to the nearest 250 gpm

Conflagration Analyisis Study

Short Description: This study points out that the methods used to develop Occupancy Hazard Classifications at the time of the study (1970) are both inaccurate and inadeqaute to be suit the purposes for which they were designed. The results of this study indicate that the concept of fire loading is vastly overrated as a determinant of fire hazard level. It is suggested that the methods described be replaced with a new quantitative measure of the occupancy fire hazard.

Title: "A Study of the Validity of Occupancy Hazard Classifications In Sprinklered Occupancies, and a Proposed Method for Occupancy Hazard Determination."

Author: Alan I. Gomberg

Organization: College of Engineering, University of Maryland

Bibliographical Data: Alan I. Gomberg, "A Study of the Validity of Occupancy Hazard Classifications in Sprinklered Occupancies, and a Proposed Method for Occupancy Determination." College Park, (MD): Unpublished paper prepared for the Fire Protection Curriculum, 1970.

Summary:

This study is intended to demonstrate the need for research in the area of Occupancy Hazard Classifications, and not to make sweeping recommendations for immediate changes in this area. The origins of most tables of Occupancy Hazard Classifications, and the methods by which these tables were derived are unknown. It is assumed, therefore, that the Occupancy Hazard Classifications in use at the present time in the various states have no justification save that of long usage. These Classifications determine to a considerable extent the insurance rate of a risk, and because of this importance it is felt that the various classifications should be justified in some way, It is the purpose of this study, therefore, to justify or refute the prsent Occupancy Hazard Classifications on the basis of past fire loss experience, and to determine a pilot method, in the form of a formula, for determining the Occupancy Hazard Classification on a flexible justifyable basis which will eliminate personal judgement to a considerable extent in favor of factual analysis.

The study develops a new concept for relative fire loading based upon both the fuel load value and the fire severity value. This concept is later reported from continuing work at the National Bureau of Standards and incorporated into the Mass Fire Spread Methodology.

While little definitive information is given relative to conflagrations, it is noted that the mapping of potential conflagrations should include rate of fire spread and direction of fire spread. The map should also show the relative potential for fire spread by adjacent areas (blocks). The map should also be orientated to natural firebreaks and should be clearly marked to indicate first, second, third, and fourth lines of defense for potentially stopping the fire spread. The only variable mentioned in this context is the construction and height of buildings.

Finally, it should be noted that the author subscribes to the position that all disasters can best be explained and predicted in relation to some form of severity index. The severity index is important to establishing a proper perception of the risk and the requirements to cope with the risk. Severity indexes can also be effectively used in mitigation of the problem.

Conflagration Analysis Study

Short Description: Foster offers the first comprehensive book on disaster planning. While this test does not give significant treatment to conflagration type analysis, it does provide important reflections and concepts on risk analysis and planning methodologies that impact on conflagration analysis; this is especially true as it relates to special distribution mappings of potential problems.

Title: Disaster Planning - The Preservation of Life and Property

Author: Harold D. Foster

Organization: University of Victoria

Bibliographical Data: Harold D. Foster, Disaster Planning. New York: Springer - Verlag, 1980.

Summary:

While the text specifically relates to planning efforts required for a selected list of disaster conditions, it only barely touches on the fire conflagration. The attention is obviously to natural disasters and airborn disasters. However, the planning techniques used for the assessment of community risk are quite applicable to conflagration analysis. The basic methodology centers on several mapping techniques.

Foster indicates that there is considerable data on past frequency and intensity of impact for selected disasters and this is indicated to include conflagrations. Once the data has been collected it can be displayed on a series of maps. These maps then become valuable for forecasting a specific type of disaster and promoting the adoption of strategies to avoid them. This information may require further analysis through the use of one or more predictive models, before the goal can be fully achieved.

The author notes that the analytical process for many hazards may be limited, similarly, for some events the past may not be a sufficient guide to the future. Nevertheless, planning decisions are being made daily, based on incomplete information. For this reason, it is essential to use the data on risk that is available, even if it is not as detailed or as comprehensive as might have been.wished.

Once the information has been collected to aid in the delineation of risk, it becomes possible to map vulnerability. For analysis and operations on conflagrations scales of 1:100 and 1:500 are recommended. After careful consideration, the one purpose maps are recommended for disaster planning. In other words, it is not appropriate to combine a hazard map showing conflagration potential with a hazard map showing flood potential.

Conflagration Analysis Study

Short Description: A hypothetical, but not infeasible, fire defense system for a metropolitan area under nuclear attack conditions, developed in an earlier study, is examined for operability in an assumed situation at San Jose, California. The analysis concluded that with adequate thermal hardning and citizen self-help, the system would be effective and the conseuqences of the attack would be minimal. Additional refinements for the basic system were developed during the study.

Title: Fire Defense Systems Analysis: Application of Concepts to the San Metropolitan Area.

Author: Lester Eggleston

Organization: Southwest Research Institute

Bibliographical Data: Lester Eggleston. Fire Defense Systems Analysis: Application of Concepts to the San Jose Metropolitan Area. San Antonia, (TX): Southwest Research Institute, Final Report Contract No. DAHC20-70-C-0210 for the Office of Civil Defense, Office of the Sectretary of the Army, Washington, D. C. October 1960.

Summary:

Obviously, since physical damage and destruction by fire are inevitable in any nuclear attack, the defense system should be judged on the basis of how effectively it can reduce the losses to some unavoidable minimum. There appears to be unanimous agreement that if a typical unprepared American city of dominantly combustible construction were to be attacked, existing computer programs and technical studies would permit prediction of ignitions and subsequent fire spread. All such studies have indicated that the demands for fire defense would completely overwhelm the facilities and manpower which municipalities can afford to provide for peacetime requirements. In addition, the performance of the fire services could be expected to be degraded by blast effects, fear of radiological hazards, refugee traffic, debris, and the possbile buildups of mass fire. The net result might be described in a mathematical model as widespread ignitions, continuing through a number of spread generations to burnout, and a discouraging history of futile defense actions. The area would suffer widespread devastation and present a difficult problem of survival for the population.

This case study indicates that a passive population seeking temprary safety in shelters and relying upon others to protect them is essentially an undefended one, exposed to the maximum threat against its survival. The hypothexized defense system assumes a total effort on the part of the population, actively engaged first to minimize the weapons effects, then taking immediate actions against ignitions during the initial phases when they are still well within self-help capabilities. Backed up by the special skills and equipment of the organized fire services, it appears that the fire threat would be so greatly reduced that almost every structure not damaged beyond possible use by the blast wave would continue to be available for population survival and rpaid recovery.

Conflagration Analysis Study

Short Description: A variety of wall and ceiling panels in a full scale room corner were exposed to a fire from a standardized wood crib, simulating the environment produced by the burning of a single item of furniture, to evaluate their contribution to room fire growth. A temperature range of 450 to 650°C appears to be the boundary layer between limited and full involvement. For purposes of the mass fire development study, these parameters are important to an understanding of the fire scenario that will lead to the potential mass fire development.

Title: Fire Buildup in a Room and the Role of Interior Finish Materials

Author: Jin B. Fang

Organization: Center for Fire Research, National Bureau of Standards

Bibliographical Data: Jin B. Fang, Fire Buildup in a Room and the Role of Interior Finish Materials. Washington, (DC): Center for Fire Research, Institute of Applied Technology, National Bureau of Standards, June 1975.

Summary:

The study conclusions are based on a limited series of full-scale fire growth tests in a room and corresponding small-scale laboratory tests on a series of wood and gypsum board-base wall and ceiling lining materials. The objectives were (1) to evaluate the extent of fire growth attributable to the interior finish materials when exposed to a typical low intensity fire source, and (2) to assess possible correlations between fire behavior during the fire buildup process and numerical values from standardized laboratory tests. Additional data, involving tests on a greater variety of wall and ceiling materials are suggested for the future.

and 6.5 x (room width + room depth) x glazing percentage for rooms with two adjacent window walls.

The program selected the room type before calculating the total window area. A_T could now be obtained by calculating the total wall and ceiling area and subtracting A_w.

(iv) Fire load density. A fire load ensity was selected and multiplied by the room area to give L.

(v) Fire severity. The fire severity K $\frac{L}{\sqrt{A_w \; A_T}}$ was calculated assuming K to be 1 (see the section on tneory).
The figures was multiplied by a conversion factor to change it from lb/sq ft. to kg/sq m and thus give the fire severity in minutes. Finally, the fire severity was given a place in a histogram.

On the basis that K = 1, Figure 3 gives the histogram of fire severities in intervals of one minute, and Figure 4 gives the histogram in intervals of 15 minutes. It shows that about 7 per cent of office rooms would require a standard fire resistance of more than one hour. This compares with Baldwin's figure 2 of 4.3 per cent based on 47 rooms.

It has been suggested[6] that the distribution might be exponential. This was found tc be so; the cumulative frequency curve for rooms having a fire severity greater than a given value approximates to the equation $p = \exp(-0.04\ R)$ where p is the proportion of rooms with a fire severity greater than a given value of R, ie the probability that any room will have a five severity greater than R. This line is plotted in Figure 5 together with the corresponding data obtained by Baldwin[6], with which it compares.

It should be noted that certain approximations and assumptions have been necessary during the course of this study; for example, the reduction of Langdon's data the subjective estimate of the distribution of room shapes, and the representative value of K. Some of these apprximations can be resolved by further data collection, but it will be more rewarding in the first instance to undertake a sensitivity analysis to assess the relative importance of the various factors, bearing in mind the stochastic nature of the other variables. This analysis will be the subject of further research.

However, the results obtained in this preliminary study are encouraging and indicate that simulation is a feasible technique for use in this field.

Conflagration Analysis Study

Short Description: This summary of conflagrations from 1900 to 1951 is prepared by the National Fire Protection Association with the hope that the records of the conflagrations assembled will offer measurable assistance to those who have attempted to enlist the same degree of public support for national fire defense now given to military defense.

Title: Conflagrations in America Since 1900

Author: National Fire Protection Association

Bibliographical Data: Staff, Conflagrations in America Since 1900. Boston, (MA): National Fire Protection Association, 1951

Summary:

This is a compendium of the conflagrations identified over a fifty year period in the United States. The following statement is offered on forcasting conflagrations.

> "Conditions advantageous to the occurrence of a conflagration can be readily recognized by fire protection specialists. Among the conditions which invite widespread destruction by fire are congested areas of combustible structures lacking fire cut-offs and exposure protection, hazardous occupancies without proper protection, dilapidated fire breeding structures, wood shingle roofs and weak public fire protection.
>
> Weather plays an important role in the development of a fire into conflagration proportions. Long hot, dry weather decreases the moisture content and from the surrounding air. High winds provide air movement sufficient to supply adequate oxygen for rapid burning. They also tend to carry close to the ground heated air currents and embers that would normally rise, and fan embers that would usually die out without harm.
>
> Terrain is important in some localities. It is a well known fact that fire spreads rapidly uphill but slowly downhill since buildings on the uphill side are exposed to heat of structures burning below them. Conflagrations have reportedly burned out at the crest of a hill but have spread around the foot of the hill and rapidly up the slope that they failed to descend.

Conflagration Analysis Study

Short Description: This paper presents a theoretical perspective on modeling fire in a single room configuration. Basically this is the evolution of the use of a two layer zone model to describe the tracing of a developing room fire. The author relates the model structure to future implications for the analysis of fire growth in buildings.

Title: An Overview of Fire Modeling

Author: James G. Quintiere

Organization: National Bureau of Standards

Bibliographical Data: James G. Quintiere, "An Overview of Fire Modeling," (Unpublished Paper from the Center for Fire Research, National Bureau of Standards, Washington D. C., March 1981)

Summary:

Attempts to model room fire problems have developed from different mathematical strategies and for different applications. One strategy is to solve, through numerical methods, the fundamental conservation equations in partial differential form. This has been limited, for the most part, to unsteady two-dimensional representations with emphasis on the fluid mechanical aspects rather than on the combustion processes. This strategy has been termed "field" modeling, the other approach has been called "zone" modeling. It also solves the conservation equations, but in an integral sense. It considers distinct, non-arbitrarily selected, zones or control volumes to which the conservation laws are applied and inter-zone transfer processes are described. Numerous algebraic and time dependent ordinary differential equations result and must be solved. The zone modeling approach has been applied to the fully developed fire in which the application has been to assess the impact of the fire on structural building componenets. In that application, a one-zone model has been used which averages the gas properties over the entire enclosure volume. Modeling of the developing fire has considered more zones in order to be consistent with the processes of early fire growth. These zones include the fire plume, an upper hot gas layer and a lower cool gas region. It is this form of modeling that appears to have immediate utility in assessing the hazard of a developing fire.

Conflagration Analysis Study

Short Description: The spread of fire from a compartment is considered as spread through a window, through a doorway, through openings associated with entry conduits, or ultimately through openings caused by deterioration of the structure shell. The literature is reviewed for each mode of spread. Emphasis is placed on the interaction of building geometry and building materials and their relationship to fire spread from a compartment. Examples are given in which mathematical design procedures or analysis could determine a fire safe design. Recommendations are presented for continued studies and practices in this area.

Title: Spread of Fire from a Compartment - A Review

Author: James Quintiere

Bibliographical Data: James Quintiere, "The Spread of Fire From a Compartment - A Review," Design of Buildings for Fire Safety, ASTM STP 685, 1979, pp. 139-168

Summary:

Studies on the nature of fire growth from a compartment have not been numerous compared to amount of work done on fire growth within an enclosure. Also the study of fire spread from a compartment is complicated by the distinct paths the fire could take. The open door, broken window, and hole or weakness 9n the shell of the enclosure serve as potential pathways for the fire. Steps could be taken to reduce the potential for such spread. These steps involve more concern about the design and construction of a building, modification with regard to fire protection and prevention of establihsed buildings, and more research to develop improved design methodology to analyze the impact of fire on the space surrounding a compartment.

It is noted that although the potential for fire spread from windows has been assessed by mathematical analysis (and in some building code regulations have been adopted), this is not the case for spread through doorways. This is especially true in the case of fire spread from a room to a corridor which may have combustible lining materials. In this case, the potential hazard is presently determined by the results of a flammability test of the lining material alone. Although it may not be possible to determine mathematically corridor fire spread perfectly or completely, it is possible to analyze the problem so that the most relevant variables are brought into focus. By refining this approach of analyzing the effect of the building configuration as well as material performance, a more satisfactory state of determining the fire growth potential could be reached.

Conflagration Analysis Study

Short Description: This study involves the continued development of computer codes to predict the initiation and spread of fire in urban areas following a nuclear attack. The modeling approach considers the interface relationships between 1) building fires, 2) firebrands, 3) firefighting, 4) fire storms, and 5) urban fire development. The parameters considered in this study are of importance to the quantitative analysis methods for determining the relative potential of predicting a conflagration.

Title: Fire Spread Model Adaptation

Author: Arthur N. Takata

Organization: Illinois Institute of Technology Research Institute

Bibliographical Data: Arthur N. Takata, Fire Spread Model Adaptation, Chicago: Illinois Institute Research Institute, 1972 (Prepared for the Defense Civil Preparedness Agency - Final Report IITRI - J6263

Summary:

Specifically, in this study, provisions were made in the computer codes to reflect recent improvements (1970-1972) in the state of knowledge in regard to firebrands, effects of blast on ignitions caused by fireball, and shielding of interior building fuels from exposure to the fireball by trees, bushes, and awnings. Also allowances were made in the codes for buildings that contain room fires as well as for evaluating the consequences of removing window coverings or room items from exposure to the fireball. Detailed discussions of all the changes are included as well as an overall discussion of major features of the codes. Input/output data are described for each code.

The analytical studies included the following specific categories:

1. Firebrands,

2. Room flashover,

3. Thermal shielding, and

4. Active countermeasures.

This study is especially important to the conflagration study because of the special focus given to the element of firefighting. Firefighting is accounted for in the code and provides for variations in the numbers of self-help teams, brigades and fire department units as well as the deployment of each type of unit throughout the urban area. Allowance is made for delays in leaving shelters, travel times and times to suppress fires. Because of possible debris, provisions are also made for varying the travel items with distance from ground zero. Finally, it is possible to direct fire department units to critical fire areas at specified times.

The principal results of upgrading the code are:

1. Drastic reductions in the number of sustained building fires caused by the fireball by a factor of as great as five. These reductions are primarily a consequence of extinguishments by the blast and to a lesser extent due to shielding by trees, bushes, and awnings.

2. A reduction of roughly two in the numbers of fires spread by firebrands for wind velocities under 15 miles per hour.

Finally, it is observed that, these reductions in the initiation and spread of fire makes fire-fighting an even more viable tactic than was determined in earlier studies. In conclusion it was found that firebrands are not capable of sustained fire spread unless fires are also spread by radiation. This is not to discount the fact that firebrands provide the only important mechanism of fire spread across major firebreaks but rather to reemphasize the fact that fire-fighting by substantial number of citizens soon after a nuclear burst can appreciably moderate subsequent fire damage.

Conflagration Analysis Study

Short Description: This is the first in a series of studies conducted by IIT Research Institute designed to evaluate public fire fighting operations. It is an important study concerning establishing a methodology for studying the variables associated with fire spread in structures. Basically, this is a study of the characteristics of fire spread from incipient stage to full involvement of a structure or structures including the effect of extinguishment efforts during the various stages of development.

Title: Operations Research Study - Extinguishment of Building Fires

Author: Willis G. Labes

Organization: Illinois Institute of Technology Research Center

Bibliographical Data: Illinois Institute of Technology, Chicago, Illinois, 1966.

Summary:

This study develops a methodology for recording the "story" of a structural fire. Information is developed on how fire fighting operations are performed under a variety of field conditions. The primary body of data consists of information extracted from reports on 73 fires in Chicago, Illinois. Useful correlations between hte following parameters are presented:

1. Water application rate density for control vrs. Fire Area.
2. Water application rate for control vrs. Fire Area.
3. Fire control time vrs. Fire Area
4. Man hours expended for the completer fire fighting operation vrs. Fire Area
   Note: In this case the fire area represents the maximum floor area of the space involved in the fire.

The fire story is a case history of the fire as a time function analysis. This includes:

A study of the characteristics of fire spread from initial combustion to full involvement considering the time factors from discovery, discovery to alarm, alarm to arrival of major fire fighting units, arrival to initial water extinguishment, application to control, and control to final extinguishment, incluidng overhaul; also observations pertaining to the use and apparent failure of portable fire appliances by building occupants or emplyees during the initial phases of the fire. The effects of construction, occupancy, exposure, and weather conditions on fire spread are also evaluated. Rates of water discharge during various fire stages and total quantity of water are estimated.

This study reinforces the premise that a suitable way of studying and predicting the structural fire phenomena is through the use of a time line analysis. The burn history curve is adaptable to develping an analytical relationship between preburn time, control time, extinguishment, and overhaul time. Therefore, the process of fire development, control, and extinguishment or burnout are

directly related to the curve structure. This concept clearly demonstrates that the factoral analysis used in burn history curve development is applicable to conflagration block rating analysis.

Labes presents a very comprehensive set of factors that enter into any equation of fire spread in buildings and between buildings. The factors divide into two categories: general environmental conditions; and structural interrelationships. The sub categories repectively are:

Set 1: General
1. Type of occupancy
2. Weather conditions

Set 2: Structure
1. Construction type
2. Wall materials
3. Floor and floor covering
4. Roof construction and roof covering
5. Interior wall and ceiling finish
6. Floor openings
7. Exterior wall exposures
8. Special superstructures and construction
9. Functional use of occupancy in relation to the structure
10. Age of the Structure

Conflagration Analysis Study

Short Description: The document is a collection of translated records on the firestorm conditions that occurred in Hamburg, Germany during World War II. The documentated demands placed on the German fire service appear to be of interest to the development and refinement of an Urban Conflagration model.

Title: Fire Fighting Operations in Hamburg, Germany During World War II.

Authors: Carl F. Miller

Organization: Department of Defense

Bibliographical Data: Carl F. Miller, Fire Fighting Operations in Hamburg, Germany During World War II: Excerpts From the Hamburg Fire Department Documents on the Air Attacks During World War II.

Summary:

To obtain and preserve valuable untranslated records of the large fires resulting from air attacks in World War II, the Defense Civil Preparedness Agency sent Dr. Carl F. Miller and Mr. James W. Kerr to Germany in 1965. They found, and obtained permission to publish, a number of documents and photographs, particulary of the mass fire in Hamburg, Germany. These documents have been translated and analyzed and a number of reports concerning them have been published. The sited report contains the remaining translations and pictures considered worth preserving for those studying the effects of large fires.

Relative to the conflagration analysis process, the Hamberg reports are usefull in assessing the incapability of "fire brigades" in containing and extinguishing the mass fire phenomena. It also documents the extreme fire condition created when individual fires coalese into a mass fire. Furthermore, recognition of the fire storm wind velocities and patterns must be considered in the conflagration assessment. Finally, the reports give some very clear indicators of the problems created by flying brands in starting spot fires and remote fires. The information gathered in these reports is important to the predictability of fire spread in the mass fire phenomena.

Conflagration Analysis Study

Short Description: This report compares three fire spread models, developed in 1970 for the Office of Civil Defense, for utility, accuracy and efficiency when applied to Civil Defense fire information requirements. The fire spread modeling was essentially limited to the radiation fire spread mechanism. All three models provided procedures for calculating fire spread under a limited range of conditions, but all suffered to some degree from inadequate modeling of urban configurations and the fire parameters associated with urban structures that significantly affect fire spread mechanisms.

Title: Evaluation of Systems Fire Development

Author(s): Leo W. Weisbecker and Hong Lee

Organization: Standford Research Institute

Bibliographical Data: L. W. Weisbecker and H. Lee, Evaluation of Systems Fire Development, Menlo Park, California: Standford Research Institute, (SRI Project 6250-060 -- OCD Work Unit 2619A) 1970.

Summary:

The study recommends that a "reference" fire spread model be structured for evolutionary development. Although none of the models considered could provide a sufficiently broad base upon which a reference model could be built, parts and concepts from all three models could be incorporated. The reference model, according to the authors, should be structured in terms of fire spread mechanisms by developing five spread submodels that are then analyzed at the most basic level and subsequently systematically broadened in scope. Models for specific purposes and having predictable characteristics can be derived from the "reference" model by making appropriate simplifying assumptions.

For purposes of the conflagration study, it is important to examine this study report in relation to radiation fire spread. The basic input parameters of radiation fire spread were discussed and compared. The radiation fire spread model is compared through submodels; the parameters and inputs of the three models are compared in Table III (copy attached). In general, there was little agreement on what constituted the effective area of a burning structure. Effective area differences in excuse of a factor of 4 appear to be common. A difference of a factor of 4 in area can readily be translated to approximately a factor of 2 in the theoretical critical distance.

The most critical, most difficult, and most important consideration in urban fire spread modeling is the characterization of the submodels to urban configuration. The procedures used in the three models discussed is not fully reported. The commonality rests with the input data. The inputs to the effective source area submodel are:

1. Roof: size, shape, materials

2. Wall: size, shape, materials, windows

3. Building: construction, materials, contents

4. Meteorology: wind, humidity, precipitation rate

5. Receiver: exposure angle

The study concludes that the importance of each input varies, and the importance of each input may even vary from structure to structure, necessitating special handling of exceptional cases. Before a decision is made to eliminate an input modifier, the effects of its elimination should be ascertained.

Bibliography

Study Phase II

1. Bird, Eric L. and Stanley J. Docking. Fire In Buildings. London: Adam & Charles Black, 1969 ed.

2. Butler, C. P. Camp Parks Mass Fires. San Francisco (CA): U.S. Naval Radiological Defense Laboratory, OCD Work Unit 2561A, Autust (CA) 1969, Final Report.

3. Butler, C. P. Operation Flambeau - Civil Defense Experiment and Support. San Francisco (CA): U.S. Naval Radiological Defense Laboratory, OCD Work Unit 2536G - NRDL-TR-68-143 - 19 July, 1968.

4. Countryman, Clive M. Project Flambeau: An Investigation of Mass Fire. Final Report, Volume 1. Berkeley (CA): Pacific Southwest Forest and Range Experiment Station. OCD Work Unit 2536A, 1969.

5. Daenzer, Bernard J. Fact-Finding Techniques in Risk Analysis. New York (NY): American Management Association, Inc. 1980.

6. Department of Defense. Federal Civil Defense Guide on Local Assessment of the Conflagration Potential of Urban Areas. Part E. Chapter 10, Appendix 1, Annex 1, July 1969. Washington (DC): Department of Defense.

7. Egan, David M. Concepts in Building Fire Safety. New York (NY): John Wiley & Sons, 1978.

8. Factory Mutual System. Handbook of Industrial Loss Prevention. Second Edition. New York (NY): MacGraw-Hill Book Company, 1967.

9. Fung, Francis C. W. Fire Endurance Thermal Analysis of Construction Walls. Washington (DC): National Bureau of Standards Report 10-494, September 29, 1971.

10. Kashiwagi, Takashi. "Effects of Attenuation of Radiation on Surface Temperature for Radiative Ignition", Combustion Science and Technology, 1979, Vol. 20, pp. 225-234.

11. Lee, B. T. Modeling Individual and Multiple Building Fires. Menlo Park (CA): Stanford Research Institute, DCPA Work Unit, 2561H, SRI Project PYU-8150, 1972.

12. Leir, G. Williams. Approximations for Spatial Separation. Fire Technology, Volume 22, May 1966.

13. Lommasson, T. E., J. A. Keller and R. G. Kirkpatrick. Firestorm Analysis. Albuquerque (NM): The Dikewood Corporation, 1977.

14. Marchant, E. W. Fire In Buildings. Great Britain: Harper and Row Publishers, Inc. Barnes and Noble Import Division, 1973.

McGuire, J. H. Fire and the Spatial Separation of Buildings. Canada: National Research Council, Division of Building Research, November 1965.

McGuire, J. H. Heat Transfer by Radiation. London: Department of Scientific and Industrial Research and Fire Officers' Committee, Charles House, Special Report No. 2, 1972.

National Fire Protection Association. Standard 80A - Protection from Exposure Fires. Qunicy (MA): National Fire Protection Association, 1983.

National Academy of Sciences. Fire Safety Aspects of Polymeric Materials. Washington (DC): National Academy of Sciences, 1978 - NMAB 318-4.

Nielsen, Hugo J. Origin and Properties of Fire Whirls. Chicago (IL): Engineering Mechanics Division, Illinois Institute of Technology Research Institute, 1969 (2536H).

North, M. A. The Estimated Fire Risk of Various Occupancies. Borehamwood, (England): Hartfordshire, Fire Research Station, Wd6-2BL, F.F. Note No. 989, October 1973.

Palmer, Thomas Y. Project Flambeau: An Investigation of Mass Fire - Volume II. Berkeley (CA): Pacific Southwest Forest and Range Experiment Station, 1969.

Quintiere, James. "Spread of Fire From a Compartment - A Review", Design of Buildings for Fire Safety. ASTM STP 685, E. E. Smith and T. Z. Harmathy, Eds, Philadelphi (PA): American Society for Testing and Materials, 1979, pp. 139-168.

Ryabov, I. V., A. N. Baratov, and I. I. Petrov. Problems in Combustion and Extinguishment. (Translated by: K. L. Awasthy) Springfield (VA): National Technical Information Service, 1974.

Smith and Harmathy (eds). "Design of Building for Fire Safety", (A Symposium sponsored by ASTM Committee E05 on Fire Standards, 27 June, 1978). American Society for Testing and Materials, Philadelphia (PA).

Son, B. C. and J. B. Fang. "Fire Spread on Exterior Walls Due to Flames Emerging From a Window in Close Proximity to a Reentrant Wall Corner". Washington (DC): Center for Building Techmology, Institute for Applied Technology, National Bureau of Standards, PB 225-286, April 1973.

Storey, Theodore G. et. al. Project Flambeau: An Investigation of Mass Fire - Volume II. Final Report. Berkeley (CA): Pacific Southwest Forest and Range Experiment Station, 1969.

Takata, Arthur N. Mathematical Modeling of Fire Defenses. Chicago (IL): Illinois Institute of Technology Research Institute, 1969.

. Takata, Arthur and Frederick Salzberg. Development and Application of A Complete Fire Spread Model. Chicago (IL): Illinois Institute of Technology, 1968.

. Vodvarka, Frank J. Firebrand Field Studies. Chicago (IL): Illinois Institute of Technology, 1969.

. Vodverka, Frank J. and F. Slazberg. Full Scale Burns in Urban Areas. Chicago (IL): Engineering Machanics Division, Illinois Institute of Technology Research Institute, June 1969.

. Vodvarka, Frank J. Urban Burns - Full Scale Field Studies. Chicago (IL): Illinois Institute of Technology Research Instutute, January 1970.

Literature Synopsis

The work of Vodvarka, Salzberg, and Takata at the Illinois Institue ' Technology Research Center identifies a number of important considera- .ons and variables associated with the phenomena of fire spread between :ructures over defined gap widths. (27, 28, 29, 30) The importance of ıis work includes the following notations: 1) Fire spread rate within single building is the predominant factor in analyzing radiation emitted :om that building and the wave pressure exerted from that building. 2) ıdiation and pressure are key variables in analyzing the fire spread phe- ɔmena between structural "faces". 3) The time to control the spread of ire problem is directly proportional to the fire severity index of the ex- ɔsing structure(s). The radiant energy factors developed in this work are f importance to the quantitative analysis of fire spread between structures. he pressure function that can create a heat wave is a very complex formula- ion that does not appear to lend itself to simplification for the purpose f local assessment analysis.

Son and Fang discuss the issue of fire spread from exterior walls ased on flame emergence from window areas. (25) From extensive testing onditions it appears that the critical variable in the relationship of indows and walls is the interior fuel load parameter. For example there s very little irradiance when the fuel load is below 4.4 pounds per square ɔot of floor area. The critical zone is between 4.4 lbs/ft^2 and 6.3 lbs/ft^2. bove the upper limit, the radiation level is predictable and presents a nown threat to exposed objects.

agration Analysis Study
II

Description: Project Flambeau, a research activity of the Pacific
ıwest Forest and Range Experimental station, was an exploratory study
mass fire behavior. Six test fires were burned on isolated sites in
ornia and Nevada. Instrumentation was developed and tested con-
ntly with the burning of the fires. This summary report of the work
oject Flambeau from 1964 to 1969 outlines that periods knowledge of
fires; suggests some of its characteristics; describes the research
ach use and development of instrumentation; discusses the results
ned; suggests a definition of mass fire; and offers a prescription
n experimental mass fire.

: Project Flambeau

r: Clive M. Countryman

ization: Pacific Southwest Forest and Range Experiment Station

iographical Data: Clive M. Countryman, Project Flambeau: An Inves-
tion of Mass Fire. Final Report - Volume 1. Berkeley: Pacific South-
Forest and Range Experiment Station. OCD Work Unit 2536A, 1969.

ary:

Project Flambeau was an exploratory study into mass fire behavior. The
arch was conducted by the Pacific Southwest Forest and Range Experiment
ion, Forest Service, U.S. Department of Agriculture, for the Office
ivil Defense, U.S. Department of the Army, and the Defense Atomic Support
cy, U.S. Department of Defense. The objectives of Project Flambeau were

- Determine the minimum size of fire and fuel loading at which mass fire, and particularly fire storm effects, occur, so as to provide a "standard" mass fire for future and more sophisticated studies.
- Explore the instrumentation problem in mass fire research, and develop instrumentation for such experimental work.
- Acquire as much quantitative information as possible on fire systems, particularly in those areas of primary interest to civil defense problems.
- Test the validity of the descriptive model of a simple mass fire system. Six experimental or test fires were burned at isolated sites along the California-Nevada border from 1964 to 1967 (table 1).

Carbon monoxide	80 minutes
Air temperature	90 minutes
Thermal radiation	3+ hours
Lachrymator gases	6+ hours

One Day Threshold

Oxygen depletion	0 minutes
Carbon dioxide	5 minutes
Street visibility	60+ minutes
Air temperature	2 hours
Thermal radiation	3+ hours
Carbon monoxide	4+ hours
Lachrymator gases	6+ hours

The principal conclusion of this work is that the ERT's for the one hour sholds are all equal except for oxygen depletion and carbon dioxide. the one day threshold, the ERT's extend up to 6+ hours, with carbon xide the most serious.

lagration Analysis Study
II

t Description: Mass fires in cites, ignited by a nuclear detonation in atmosphere pose serious life hazards. While there is a mass of information he pyrolysis of cellulise, flames and flame temperatures, and small ratory crib fires, there are almost no quantitative data on the dynamic vior of large fires. Neither cites nor forests are ever instrumented, so the only data on mass fires are those obtained from eye witness accounts urvivors.

e: Operation Flambeau - Civil Defense Experiment and Support

ıor: C. P. Butler

ınization: U. S. Naval Radiological Defense Laboratory

iographical Data: C. P. Butler, Operation Flambeau - Civil Defense riment and Support. San Francisco: U. S. Naval Radiological Defense ratory, OCD Work Unit 2536G - NRDL-TR-68-143 - 19 Jule 1968.

ıary:

Operation Flambeau, a series of large instrumented fires, has been iated to solve this problem. Each of these fires is an array of fuel s, composed of 20 tons of pinyon trees, laid out in a geometrical pattern ılating the fuel distribution in a typical urban residential development. ensity-time data were measured at street level for the principal causes life hazards, i.e., oxygen depletion, carbon dioxide concentration, carbon xide concentration, air temperature, thermal radiation, street visibility lachrymating gases.

The Escape Restraint Time (ERT) is the time interval during which a life ırd equals or exceeds some fixed threshold for deleterious effects on the ın body. These effects are anoxia due to oxygen depletion, carbon dioxide ıysia, carbon monoxide poisoning, intolerable thermal radiation, heat proıtion due to high temperatuers, loss of visual contact with the local ironment due to low street visibility and temporary blindness due to ırymating gases.

Two ERT's have been calculated for each hazard, one based on a threshold ıe for one hour survival and the second at a threshold value for one day rival, both at a continuous exposure. The hazards are listed in order increasing severity.

ıary of Escape Rastraint Times for Life Hazards in Flambeau Fire 760-12.

One Hour Threshold

Oxygen depletion	0 minutes
Carbon dioxide	0 minutes
Street visibility	60+ minutes

Finally, the dynamic burning characteristics of 1/16 scale plywood els of the Camp Parks barracks section are as follows:

1. A scaled distance of 7 feet between two models increases the burning rate by a factor of 2 as compared to scaled 25 feet.

2. The ratio of total thermal radiation to the total energy release rate of maximum burning rate time is 30% for unskirted models, 25% for skirted models, and 8% for the full-scale building.

3. Carbon monoxide exceeds threshold[3] (100 ppm) 15 minutes after ignition in a skirted model basement and between two models at scaled street level distances in about the same time.

onflagration Analysis Study
art II

hort Description: This report summarizes experimental work on the dynamic haracteristics of burning buildings, as studied with small plywood models nd one full-scale barracks section. Parameters measured include total nergy release rate, total thermal radiation, and carbon monoxide concenrations at scaled street levels, as well as carbon monoxide concentrations n a model basement.

itle: Camp Parks Mass Fires

uthor: C. P. Butler

rganization: U. S. Naval Radiological Defense Laboratory

ibliographical Data: C. P. Butler, Camp Parks Mass Fires. San Francisco: J. S. Naval Radiological Defense Laboratory, OCD Work Unit 2561A, August 1969, Final Report.

Summary:

The mass fire scaling under evaluation by Lee at SRI is based on partial scaling principles neglecting the molecular transport parameters, as characterized by the Grashof number. The rules require that the model be geometrically similar to the full scale and that the heat release per unit area, q/L^2 be scaled as the square root of the characteristic horizontal dimension L. To the extent that these principles are valid gas temperatures will be the same and the velocity will scale as $L^{1/2}$ at homologous points of both the model and the full scale. Employing measurements at elevations from 6 inches to 50 feet over a 30 acre fire at Flambeau, Lee has demonstrated the validity of these principles by using data from homologous points over a 4 foot by 4 foot model.

Geometrical scaling of wood structures includes the fuel loading which scales as L^3. If the heat release per unit area, q/L^2, should also scale as the $L^{1/2}$, then we should find that the velocity and time should scale in the same manner as that for a mass fire. However, there is no assurance that q/L^2 will scale as $L^{1/2}$, since the burning characteristics of wood fuels arranged in a building structure may not behave in the same manner as the wild-land fuels used in the Flambeau fires.

As mentioned earlier in this report, one of the objectives of this work at Camp Parks is to measure the sensitivity of each parameter in modeling large structural fires and the role each plays in fire spread.

The final ratios of total thermal radiation to total energy release rate at maximum burning time are: for a skirted mode, 25 percent; for an unskirted model, 30 per cent; and for the full-scale barracks section, 8 per cent.

The danger here is moderate. On the perimeter one finds twentieth century suburban development where ground coverage does not exceed 15 per cent and may be as little as 5 per cent, i.e. 10 to 12 houses to the acre; in this last category, though the houses themselves may not be fire-resisting, they are so widely spaced that, with reasonable fire fighting, conflagration is almost impossible.

In addition are the industrial and other specialized areas which must be considered separately. Their risks may be high or low according to the nature of the predominating industry or use, and each must be treated on its merits.

To some degree, overall hazards in Victorian English manufacturing towns have been kept down by the custom of surrounding each high risk factory with an area of low-risk workers' dwellings. This practice is, of course, at variance with modern town-planning principles; the modern practice of gathering factories together into industrial estates increases the fire risk and therfore demands special care in the provision of fire-fighting services and the planning of fire breaks between buildings or groups of buildings.

The average height of building conditions the fire load per sq. ft. of land. Where buildings are made high as a compensation for restricting ground coverage the arrangement may reduce the conflagration hazard; but in itself increase in height brings greater danger from collapsing buildings, added difficulties in fire fighting at high level - e.g. less water pressure, taller ladders, flames and smoke from below - and a greater area of window exposure from building to building.

The fire division pattern of the built-up area gives the basis for surrounding and limiting a fire or conflagration. It is composed of (a) open spaces and (b) fire-resisting walls which will form constant barriers to fire spread. It is rarely that a town has an ideal fire division pattern, i.e. a system of barriers which in themselves are so complete as to prevent fire spread; but even an imperfect pattern is of great value if properly recognized and exploited by fire fighters.

Natural Conditions

Although variations between the natural conditions in towns in any one country may not have a major effect on their fire-susceptiblity, such variations in different parts of the world are of great importance. For instance, the average relative humidity of London ranges between 73 per cent (early summer) and 87 per cent (early winter) and as a result the moisture content of wood here lies between 15 per cent and 21 per cent. That is because Great Britain is a relatively small island. In central continental areas the average humidity may range between 35 per cent and 73 per cent, the consequent moisture content of wood lying between 7 per cent and 15 per cent, so that materials which in London are regarded as bulk fuel may in very dry areas become tinder! These figures are for wood outside buildings; indoors the moisture content is usually appreciably lower.

Steep contours, as in hilly towns, raise some buildings over others and thus make them more vulnerable to fires burning in the valleys. Meanwhile the drawing of water in the valleys for fire fighting may deprive the hilltop mains of the supply necessary to combat fires in the higher buildings.

Wind will determine the direction in which a fire tends to spread and, equally important, the side on which it is less likely to spread; it can carry burning brands for great distances. The direction of the prevailing wind is therefore important in relation to the siting of important buildings especially on the outskirts of a town, whether they be hazardous in themselves or susceptible to other fires.

Conclusion

A study of the combined influence of these various factors on English towns has shown that in town centres of medieval origin the ground coverage may reach 75 per cent, and there is a constant conflagration hazard even in peace-time. Growth under the by-laws and customs of the nineteenth century did not usually reach a ground coverage in excess of 45 per cent.

Conflagration Analysis Study
Part II

Short Description: This is a rare text in that it devotes a complete section to the urban conflagration hazard. The characteristics of this type of fire are presented in relation to occupancy and structural factors. The factors which determine the fire hazard in individual buildings has been fully identified in the literature. Since the town is an agglomeration of individual buildings, so the fire susceptability of the town as a whole must depend to a major extent on an aggregation of these individual risks. There are, however, additional factors, some artificial, some natural, which relate rather to the town as a whole; this is the subject of the stated book section.

Title: Fire In Buildings

Authors: Eric L. Bird and Stanley J. Docking

Organization: Department of Scientific and Industrial Research.

Bibliographical Reference: Eric L. Bird and Stanley J. Docking, Fire In Buildings. London: Adam & Charles Black, 1969 ed.

Summary:

The overriding artificial conditions are described as "builtupness and the fire division pattern." "Builtupness," the degree to which a piece of land is built upon, has three characteristics:

1) The proportion or percentage of ground built on.
2) The pattern formed by this ground cover; and
3) The intensity of development, that is, the height of the buildings which determines the volume of building per sq. ft. of land built on. This closely related to the floor space index.

The proportion of ground coverage was especially important in war time as it determined what proportion of bombs dropped were likely to hit buildings. It is important at all times as determining what proportion of land is covered by a potential fire train and what proportion by potential fire-separation and fire-access.

The ground pattern is of great importance in determining the likelihood of fire spread and the opportunities for fire-control. If the coverage is in compact blocks separated by open spaces there is less chance for a fire to spread than if, as usually happens, the buildings sprawl along in a lace-like pattern without wide space-barriers between one part and the next. Moreover, from the point of view of fire fighting, a pattern with numerous small internal courts means that must of the property is almost inaccessible; also if all the streets are narrow it means that fire appliances will be threatened where they stand, or as they pass, with fire from overlooking buildings.

Cross Reference of Fire Spread Variables

Figure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Exposing Fire Conditions:																															
Construction - Exterior Walls	X				X		X	X	X					X			X				NA				X			X	X		
Construction - Roofs					X	X		X						X			X				"										
Height - Width of Exposure	X				X	X	X	X				X		X			X				"		X								
Percent of Wall Openings					X	X		X	X					X			X				"										
Ventilation Characteristics														X			X				"										
Fuel Dispersion				X	X									X	X		X		X		"		X						X	X	
Building Geometry	X				X			X						X	X		X				"		X							X	
Thermal Properties of Exposure		X	X	X	X	X	X		X	X		X	X		X	X	X	X		X	"	X		X	X	X	X			X	X
Exposed Building Conditions:																															
Construction - Exterior Walls	X				X			X	X					X			X				"				X			X	X		
Construction - Roofs								X			X			X			X				"										
Height - Width of Exposure					X			X						X			X				"		X								
Percent of Wall Openings					X			X	X					X			X				"		X								
Protection of Openings								X						X			X				"										
Internal Exposure											X			X			X				"								X		
Thermal Properties of Exposed		X	X	X	X				X	X	X	X			X	X	X	X		X	"	X		X	X	X	X			X	X
Site Features:																															
Separation Distance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Shielding Effect		X	X	X												X	X		X		"				X		X				
Wind Direction													X				X		X		"			X			X				
Temperature - Humidity	X		X	X					X							X	X		X		"			X			X				

introduced into a guidance method to be used by local government personnel. However, the identity of these veriables are charted in the cross matrix summary to this section of the literature search.

Much of the remaining literature reviewed for this study repeats basic understandings that have already been identified. However, one body of literature can be identified taht appears to narrow the focus of considerations to varibles sets that appear manageable for building a local assessment methodology. The works of Bird, Docking, and Egan can be identified with the charting of these considerations which follow: (1, 7)

1. The proportion or percentage of ground built on
2. The pattern formed by this ground cover
3. The fire resistance of walls
4. The number of openings
5. The number of stories
6. Roof classification
7. Setback distance
8. The radiating area of the emitter and receiver

These areas of concern are further refined according to the exposing fire, the exposed buildings, plus site and protection features by documentation from the National Fire Protection Association, the National Materials Advisory Board, and the Factory Mutual Engineering Corporation. (17, 8, 18) This information base is useful for developing a summary matrix that cross compares the identified variables associated with fire spread across defined separation distances. The Phase II Bibliography Cross Reference Table charts this information.

root of the height times the width of the facing building. Inversely speaking, the values may be assessed as a relative measure of exposure probability based upon hazard levels and width to height ratios.

Selected codes and standards also address the phenomena of fire spread between structures primarily from a preventive approach to the problem. An analysis of conditions by the National Fire Protection Association in this area reveals that there are two basic types of exposure conditions to be considered. (17) First, there is the problem of exposure due to radiated heat. The type of radiation may be a product of : (1) heat passing through windows or other openings in the facade of a burning building(s), and (2) heat from the flames issuing from the burning facade of a building, or (3) heat from the flames issuing from the windows of a burning building. Second, is the relationship of the heights of exposing buildings. The basic concern relates to the exposure to flames issuing from the roof or top of a burning building in cases where the exposed building is higher than the burning building. Some further thoughts on the analysis of the exposure problem as presented in codes and standards is presented at the conclusion of the study.

A number of highly theorectical pieces of research discuss the exposure fire problem. The works of Lee, Kashiwagi, Fung, McGuire, and Marchant are representative of highly complex interactive studies in this area. (11, 10, 9, 16, 14) While these works individually and collectively contribute to one's improved understanding of the fire spread phenomena and the variables associated with this phenomena, it is also obvious that the quantitative parameters under consideration are much too complex to be

the window opening will pernot the accurate prediction of radiative flux at a defined distance and hense potential exposure penetration. This work further reaffirms the maximum effective window radiation flux of 16.7 W/cm^2 specified in a design criteria for determining minimum safe didtance between buildings. However, work at the National Research Council (Canada) clearly shows that wind effects and drafts through buildings increase emissive power of the foame by a factor of 10. (15) The tightness of the building in question is the dominant variable.

The literature on fire spread to separate structures addresses a number of intervening variables. Nielsen discusses the potential influence of fire whirls as a fire spreading phenomena. (19) From a set of experimental results, the author works out a procedure for predicting the intensity of fire whirls in urban fires. This procedure is based on the way the production of vertical vorticity scales with the size and heat output of the fire and theoretical solutions for a convective vortex. While there is little question that this information is important to fire spread analysis, the complexity of the quantification appears to preclude any practical application to a local assessment analysis.

Leir identifies a computational methodology for assessing "safe distances" between buildings to prevent fire spread by radiation. (12) This work appears to be a preliminary investigation to later work performed at IIT Research Institute. (30) The computational requirements are expressed in the fromula $d = B/hw$ where: d is the distance in feet, B is the separation parameter, h equals the height of the building, and w is the width of the building. It should be further noted that B represents a parameter function that is based on the separation distance divided by the square

The Camp Parks Mass Fires identify one important consideration relative to potential fire spread between structures separated by designated streets. (2) It appears that during the first 15 minutes of a fire that exhibits external radiation, there is marked variations in the radiant flux. However, after the 15 minute free burn, the radiation flux essentially becomes a constant number irrespective of the geometric proportions, construction facing, fuel loading and wall opening characteristics. Is is concluded that the radiation intensity of a given exposure becomes a linear function of distance after the fifteen minute time interval and highly complex variable in the first few minutes of an exposing fire.

Operation Flambeau conducted by the U.S. Naval Radiologic Defense Laboratory was designed to study the dynamic behavior of fire spread in "large scale" fires. (26) Arrays of fuels were laid out in geometrical patterns to simulate fuel distribution in urban built up areas. Intensity time data were measurd at the street level plane for the principal causes of life hazard. However, one specific measure dealing with thermal radiation intensities is important to the phenomena of fire spread between structures across street widths. The reported thermal radiation thresholds were established at 60+ minutes. In other words, it takes approximately 1 hour for the thermal radiation to heat up the face area of an adjacent block sufficiently to initiate active flaming.

Quintiere's research work also addresses the phenomena of fire spread out of compartments and structures. (22) While the investigative work focuses on the reduction of fire spread from identified structural configurations, the finding can be examined in relation to the predictability of events given a specific set of identifyable conditions. It is concluded that compartment temperatures together with the emissive power of the flames above

An important focus of Smith and Harmathy's work on the design of buildings for fire safety is the fire spread phenomena from winds generated by the fire. (24) Several fire scenario are described from North American conflagrations where the wind generated by the fire exceeds 80 miles per hour; these are described as ground winds created by the inflow of cool convection to feed the fire and are measurable in relation to the thermal updraft velocity. This is a highly complex issue and again probably does not lend itself to a local government assessment process by any practical means.

In the study of wind conditions and vortex behavior on fire growth, Lommasson, Keller, and Kirkpatrick provide some important clues on large scale fire behavior. (13) The following characteristics have been extracted from known fire storm phenomena data for proper consideration in developing the fire spread model between blocks.

1. The inflow convection velocity for a fire storm ranges from 58 to 93 miles per hour. Water streams in this velocity path are useless because of the wind patterns.
2. The input convection velocity provides fresh air (oxygen) for the accelerated burning phase.
3. Once the vortex is formed in a mass fire, the radiant spread rate is significantly diminished or slowed.
4. All combustibles within the vortex ground area are consumed; no life is possible.
5. Fire brands being transmitted to remote sites present a conflagration spread characteristic not identified in the mass fire spread modeling.

Table 1. Experimental fires burned in Project Flambeau, 1964-1967, California and Nevada

Fire No.	Plot code No.	Date burned	Fuel bed spacing	Arrangement (rows)	Wind	Fuel moisture	Intensity rank[1]
			Ft.	Ft.			
1	760-1-64	1-31-64	115	3 by 3	Moderate	Moderate	3
2	760-2-69	5-15-64	25	6 by 6	Moderate	Dry	1
3	760-3-65	6-11-65	115	3 by 3	Strong	Dry	2
4	460-14-65	12-6-65	25	18 by 18	Light	Wet	6
5	460-7-66	6-14-65	25	15 by 16	Light	Dry	4
6	760-12-67	9-29-67	25	18 by 19	Moderate	Moderate to wet	5

[1]Based on flame height and fire activity in individual fuel beds.

In addition to these six test fires, preliminary fires[1] were burned to study the suitability of available fuels, to check the validity of the "external Look" approach to the study of fire behavior, and to gain insight into instrumentation needs of large test fires.

In the six test fires, multiple-fuel beds were used to simulate urban conditions. The fuel beds were built by arranging uprooted pinyon pine and Utah juniper trees in square piles covering about 2,000 square feet. Each pile of fuel was 46.7 feet on a side, averaged 7 feet high, and contained about 40,000 pounds of fuel (dry weight). Test fire sizes of 5, 15, 30, and 50 acres were arbitrarily selected. The plots, with 25-foot and 115-foot spacing between piles were built for the selected fire sizes. Fires were started by electrically igniting spitter fues and squibs.

Instrumentation was developed concurrently with burning of the test fires. It varied greatly in both kind and amount from fire to fire. Emphasis was placed on developing methods of directly and quantitatively measuring parameters of interest. In the "external" approach to study used in the Flambeau program, the parameters of interest were those concerned with the interactions of fire and environment and the changes in energy release rate with time.

The parameters measured in the test fires included (a) air flow in and around the fire area and pressure variations within the fire area; (b) thermal energy production, including mass loss rate of the fuel, temperature in the combustion zone, temperature of gases surrounding the combustion zone, and thermal radiation from the fire area; (c) gas composition, primarily concentrations of carbon monoxide, carbon dioxide, and oxygen within the combustion zone and in the "streets" between fuel beds.

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[1]Described in 1964 interim report.

Data collected were not primarily for the purpose of developing statistically valid cause-and-effect relationships. Rather the intent was to gather data which could provide the foundation for development of realistic theory on fire behavior and to provide guides to development of experimental studies, both in the field and in the laboratory. These studies would be aimed at solving fire problems with a reasonable expectation of deriving practical benefits. These objectives were largely accomplished.

Only six test fires were actually burned. And the tests were made under a limited range of fuel and environmental conditions. Data from the tests have yet to undergo rigorous analysis. Nevertheless, it is possible to draw some of the more obvious conclusions from the completed tests.

1. Fuel characteristics, including those associated with both fuel elements and fuel beds, are the major controlling factors in fire behavior. The burning fuel provides the basic driving energy for fire behavior phenomena associated with fire. How the potential thermal energy of the fuel is released may be affected in some cases by such environmental conditions as wind speed and air stability. In general, however, the thermal pulse produced by a given fuel bed will depend largely on the characteristics of the fuel and of the fuel bed itself.

2. Rate of thermal energy production is of primary importance in determining fire characteristics and behavior. The rate at which the thermal energy of fuel susceptible to combustion is produced is far more important than the size of the burning area close-spaced fuel bed fires in the Flambeau program varied in size by a factor of 11. However, air flow patterns, temperature, fire behavior, and noxious gas production were in general the same in the smallest as in the largest fires. The lower limit of fire size in which mass fire characteristics will appear was not determined with certainty. Because of the major influence of fuel characteristics this limit probably varies with fuel type. In fuels such as were used in Flambeau test fires, mass fire characteristics can be developed in fires in the order of 100,000-150,000 square feet in area. Test results strongly suggest that mass fires can be developed in a smaller area.

3. Strong airflow and turbulence develop within the fire boundaries. In all test fires burned, the strongest air flow and turbulence were inside the fire boundaries away from major influence of ambient flow. In the multiple fuel-bed fires the increase in air flow into the fire area was significantly greater than that of ambient flow. Air speeds within the fire area, however, were several times greater than the air inflow at the fire periphery.

4. Radiation is of minor importance in fire spread outside of the fire boundaries. The lack of ignition by radiation outside of the fire boundaries was marked characteristic of all Flambeau fires in this test series. Radiation as a factor in fire spread can be expected to become important only where spread by flame contact and firebrands is limited. For urban fires, of the type to be expected following nuclear attach, fire-induced turbulence within the area initially ignited will insure maximum flame contact and firebrand movement.

5. For multiple fuel-bed fires the position of a fuel bed in the array has only a minor effect on its thermal pulse pattern. In the mass loss experiment of Test Fire 6, only small differences were found in the mass loss rates for fuel beds in different positions. The differences that did appear seemed more closely related to variation in the circulation pattern within the fire area than to position of the fuel bed with respect to the fire center.

6. The Countryman descriptive model is a realistic portrayal of a stationary mass fire system. All six zones of the model appeared in two of the test fires. In other tests the convection column did not reach heights that permitted smoke fallout and convective development zones to develop. Fire behavior and associated phenomena were generally similar in the fuel, combustion, and transition zones for all fires that produced mass fire characteristics.

7. Wildland fuels may be used to simulate urban fires. Wildland and urban fuel beds are dissimilar and cannot usually be expected to produce similar fires in their natural state. But the thermal pulse produced by a burning fuel bed is dependent so much on fuel bed characteristics that it is possible to select and arrange wildland fuels to produce a thermal pulse that will be similar to that of an urban fuel, and to produce similar fire characteristics. Success in simulation will depend upon knowledge of burning characteristics of wildland fuels and thermal pulse characteristics of the urban fuel bed to be simulated.

8. Fire whirls are a consistent phenomenon in large and intensely burning fires. Fire whirls occurred in nearly all Flambeau test fires, and commonly occur in wildland fires. This phenomenon is of considerable importance in urban mass fire spread and in fire control activity. Fire whirls are likely to be of major importance in civil defense aspects of mass fire because of their destructiveness and their capability to rapidly spread fire and transport noxious gases.

9. Lethal concentrations of noxious gases occur within and adjacent to fires. High concentrations of carbon monoxide, carbon dioxide, and deficiency of oxygen were found in the combustion zone of Flambeau fires. Less severe concentrations appeared between the fires and on the fire edge. Since peak concentration of lethal gases, minimum oxygen, and peak heat occurred at about the same time, their combined effect may be greater than any one alone. Also of significance is the long time duration of carbon monoxide concentrations within the fire area that are high enough to affect a person's judgement and action, although not directly causing permanent injury or death.

Conflagration Analysis Study
Part II

Short Description: This document addresses the full spectrum of risk analysis including that functional portion of assessment that deals directly with the probability of fire spread between structures. While more qualitative than quantitative, this compilation of risk factors very nicely summarizes the risk variables associated with the fire spread problem.

Title: "Fact-Finding Techniques in Risk Analysis."

Author: Bernard John Daenzer

Organization: American Management Association, Inc.

Bibliographical Data: Bernard John Daenzer, Fact-Finding Techniques in Risk Analysis. New York, (NY): American Management Association, Inc. 1980.

Summary:

The portion of this fact-finding material on risk analysis that pertains to fire spread due to exposure problems presents a matrix type of evaluation based on a numerical index of potential severity. In other words a numerical value is assigned to each component in the evaluation on a scale of 1 to 10. 1 being a negligible problem and 10 being a severe problem. No attempt is made to determine a total impact value. The items to be considered are as follows:

1. Roof cover and construction
2. Exterior wall material
3. Unprotected openings in exterior wall
4. Compustible overhangs on exposing wall
5. Wall face area
6. Block density
7. Occupancy fuel load
8. Structural fire resistance
9. Separation distance
10. Separation combustibles (i.e. automobiles, natural cover fuels, storage materials.)
11. Separation slope
12. Exposed height in relation to exposing height.

Conflagration Analysis Study
Part II

Short Description: This work represents an extension of the original Gage-Babcock Conflagration Analysis Study. Of special interest is the second phase of the study which reflects on testing the validity of potential firebreaks. The developed methodology focuses on required separations in distance to potentially avoid fire spread between structures over a defined open space. Required separation are also addressed with respect to potential wind direction and speed.

Title: Federal Civil Defense Guide on Local Assessment of the Conflagration Potential of Urban Areas.

Author: Department of Defense, Office of Civil Defense

Organization: Department of Defense

Bibliographical Data: Office of Civil Defense, Department of Defense. Federal Civil Defense Guide on Local Assessment of the Conflagration Potential of Urban Areas. Part E, Chapter 10, Appendix 1, Annex 1, July 1969.

Summary:

This document represents an extension of work on the original Gage-Babcock Conflagration Analysis Model developed in 1965. Part One of this document is ti led a "Method for Measuring Relative Conflagration Potential of Urban Areas." This appears to be an interpretive guide to the original study. The examples are more definitive and the block sample is more complex that developed in the original study. However, there is no evidence of further validation of the original study materials.

Part Two is a "Method for Delineating Probably Limits of Conflagrations." The procedures for this portion of the paper are divided into two phases. The steps under Phase 1 are used to determine the potential firebreaks in a community which appear to be worthy of testing. The steps under phase 2 describe the procedure for testing the validity of these potential breaks. It should be noted that phase 1 may be completed in the office; Phase 2 will require both field and office work.

The concept of this work is based on the determination of whether a given fire break is of sufficient width to prevent a fire from spreading between structures over the defined distance. It does not address the probability of fire spread between structures. A step by step procedure is used to make the required separation distance calculations. The qualitative variables include: 1) Number of stories, 2) wall openings, 3) roof classification, 4) setback distance, 5) building width, 6) vacant width, 7) a multiplier based upon building characteristics, 8) a radiating area, 9) contributing factors, 10) an adjusted area, and 11) the required separation distance. It is assumed from this methodology that if the separation distance is not met, then there is the likelihood of fire spread between structures.

A second feature of this section is important. A new Table set required separation distances in feet for three defined wind velocities. The problem with this material is in the determination of which way the wind velocity is moving and the validation of the resulting number. However, this is one of the few studies that even reflects on the potential impact of wind conditions.

Conflagration Analysis Study
Part II

Short Description: This is an adjuct document to the original Gage-Babcock study on the Local Assessment of Conflagration Potential in Urban Areas. The significant contribution of this material is a section of "Testing the Validity of Potential Firebreaks." A set of charts are provided that relate wind conditions to firebreak requirements.

Title: Annex 1: Local Assessment of the Conflagration Potential of Urban Areas

Author: Department of Defense

Organization: Office of Civil Defense

Bibliographical Data: Office of Civil Defense, Department of Defense. Annex 1: Local Assessment of the Conflagration Potential of Urban Areas. Federal Civil Defense Guide. Part E., Chapter 10, Appendix 1, July 1969.

Summary:

As noted, this document is an extension of the Local Assessment Guide on Conflagration Analysis. However, this guide presents some important concepts and documentation not found in the 1965 edition of the guide. The supplemental material is concerned with firebreaks in urban areas and the required separation between buildings and block fronts to prevent fire spread across defined gaps. This information is presented in a series of charts. The calculation process is supplementary to the basic Form A completion outlined in the original analysis methodology.

Probably most important is a supplementary section on the potential effect of wind conditions at three defined velocity intervals. Unlike the other study variables the wind effect is presented as a function of relative probability of fire spread based upon the exposing wall face area and building gap. This is the only information of this type located in the reviewed literature on the potential impact of wind conditions. However, the stated model uses this information for the purposes of defining the requirements for firebreaks and does not address the issue of fire spread probability without the designated fire break conditions. In conjunction with the revised model, it appears quite possible to reconstruct the probability values through inverse ratios to establish a quantitative method for expressing fire spread potential as a function of predicted wind indicators. This work is presented in the Part II study.

Conflagration Analysis Study
Part II

Short Description: The author establishes a set of guide numbers for determining separation distances to protected exposed buildings. The inverse of these numbers appear to be useful as an indicator of fire spread probability.

Title: Concepts in Building Fire Safety

Author: M. David Egan

Organization: Clemson University

Bibliographical Data: M. David Egan, Concepts in Building Fire Safety. New York: John Wiley & Sons, 1978.

Summary:

Egan states that buildings located near a burning building are exposed to radiant and convected heat energy. Radiated heat energy can be reduced by (1) increasing the separation distance, (2) using outside sprinklers, (3) self-supporting barrier walls, and (4) decreasing (or eliminating) the area of the wall openings. Based on an analytical approach to each of these variables, a guide numbering system is developed for determining separation distances to protected exposed buildings from fire spread through equally distributed windows. Separation distances can be found by the formula:

$d = FN + 5$ where:

d = distance between buildings in feet
F = width (W) or height (H) in feet
N = guide number from table (no units)
Note: the referenced table is attached

The guide number appears to be a useful measure for correcting the basic probability of fire spread between structures over a given distance. This is true because it accounts for the most important two variables in any exposure equation: 1) Shape ratio of the exposing or exposed wall and 2) per cent of openings as a function of exposure severity. These values have to be considered in any assessment of fire spread probability over defined distances

Conflagration Analysis Study
Part II

Short Description: In 1967, the Factory Mutual System developed a method for the assessment of protection against exposure type fires. The concept was to prevent damage from fires in unsprinklered adjoining or adjacent properties. In principle, Factory Mutual notes that the protection level needed for exposure fires depends on the three following factors:

1) the possible severity of the fire in the exposing property.

2) the distance horizontally between the exposing wall and the exposing wall.

3) the position vertically of the exposed wall opening in relation to the exposure.

These three stipulated conditions serve as the foundation for structuring an exposure system classification. The study parameters have to be among the most important reviewed.

Title: Handbook of Industrial Loss Prevention

Author: Factory Mutual System

Organization: Factory Mutual Engineering Corporation

Bibliographical Data: Factory Mutual System. Handbook of Industrial Loss Prevention. Second Edition, New York: McGraw-Hill Book Company, 1967 (Chapter 8 - Protecting Against Exposure)

Summary:

This may be one of the most if not the most important review of literature pertaining to the spread of fire from an exposing building configuration to an exposed building configuration. This concept is supported by the fact that fire experience furnishes the most reliable guide for assessing the fire spread between structures over a defined distance. The protection concepts outlined in the stated "Handbook" are based on a study of several hundred exposure fires by the insurance industry over 25 years. Furthermore, the results appear to agree closely with theoretical and laboratory studies on the ignition effect of radient heat.

It is important to recognize that in general, exposing buildings with sprinkler protection do not present sufficient exposure to require special protection for the exposed buildings. Obviously this concept assumes the sprinkler system is not impaired. Alternatively, exposed buildings with internal sprinkler protection do not provide any special risk reduction from exposing fires.

Factory Mutual considers that in determining exposure protection, the irst step is to determine the possible severity from the exposing fire. he exposure classification depends on three conditions as follows:

1) Construction whether one-story or multi-story and whether the walls, roof and floors are of combustible or noncombustible materials.

2) Occupancy

3) Area in square feet per floor.

The variables identified in the methodology have been formulated into series of tables to make the following determinations.

1) Exposure building classification.

2) Recommended protection for wall openings for stories up to top of exposing building.

3) Recommended protection for wall openings for stories above top of exposing building.

4) Exposure protection: Walls at Angles 60 - 120°

5) Special Conditions:

   a. Wooden Exterior Walls

   b. Lumber Storage

The Factory Mutual work outline above represents one of the most compreiensive treatments of exposure analysis found in the literature. Furthermore, :he quantified variables have been established from historical analysis ınd therefore appear to have a higher degree of validity than some of the :heoretical models discussed in the literature abstracts.

Conflagration Analysis Study
Part II

Short Description: A general one dimensional transient heat transfer numerical program has been developed for composite building constructions with artibrary air gap locations. The complete Fortran language program used on the NBS Univac 1108 computer is given. A discussion of the program and instruction for its use are facilitated by the aid of examples. Numerical solutions using the present program compare favorably with experimental data in standard endurance tests.

Title: "Fire Endurance Thermal Analysis of Construction Walls"

Author: Francis C. W. Fung

Organization: National Bureau of Standards

Bibliographical Data: Francis C. W. Fung, "Fire Endurance Thermal Analysis of Construction Walls," Washington: National Bureau of Standards Report 10-494, September 29, 1971

Summary:

The fire performance of building constructions is generally evaluated by a large scale laboratory fire endurance test (ASTM E 119) in which one surface is exposed to fire, controlled according to a prescribed increasing temperature history simulating the burnout of combustibles. The fire endurance rating of the construction is the time period during which it withstands the fire exposure without (a) structural failure, (b) the development of cracks through which flames can cross, or (c) the temperature rise on the unexposed surface exceeding a prescribed limit (250^{o}F rise average, 325^{o}F rise at a single point). Where the failure criterion is due to heat transmission without complications due to structural or physical effects, heat transfer analysis should provide a means for prediction and design.

A particular aspect of the fire endurance test which is not well defined but which probably plays a significant role in fire performance, is the effect of mass flow (air and combustion gases) due to pressure differences since typical building constructions consist of a series of composite layers and intermediate air layers, a transient heat and air infiltration model was formulated. The program is particularly suitable for evaluating the thermal fire endurance of building constructions where various combinations of solid-to-solid and solid-to-air contacts are encountered. For each solid layer, the present program has provisions for phase changes, heat generation and absorption, and thermal property variations commonly found in building materials. Through the air spaces the modes of heat transfer include radiation and convection with temperature-dependent heat transfer coefficients and air properties. A number of analog and numerical programs for fire endurance evaluations had been in existence for some time (1, 2, 3, 4). A more flexible and general finite difference program was developed by Krokosky as recently as 1970 (5). For a review of the existing thermal analysers for fire endurance evaluation one is thus referred to (4 and 5).

ɔresent numerical program was developed to incorporate into fire endurance ɣses the following features which are desirable and yet not readily ℓable in existing programs:

1. Options to handle heat exposure on one or both sides of structure.

2. Heat balances in air spaces to allow for air infiltration, and heat generation and absorption in air spaces.

3. For ease of application to building structures as input card, say 101101, is sufficient to instruct the computer of the specified number of solid layers and air spaces in a given problem.

4. Temperature-dependent properties and known chemical heat exchanges of various building materials are stored in a subroutine and called by an input card, say 2331, where the numbers indicate coded materials stored in the subroutine.

5. Duration as well as amount of known chemical heat exchanges can be varied in any material.

ıgration Analysis Study
[I

Description: In most ignition studies, the radiant flux of external :ion to a sample surface has been measured by a flux meter at the position the sample will be located. Then, it is assumed that this measurement irradiates the sample surface and its value does not change in time ignition occurs. However, in a recent study (Kashiwagi, 1979), it was that there was strong attenuation of the external radiation by the of decomposition products (gases and particulates) of polymethyl- :ylate (PMMA) or red oak. This was observed by experiments in which laser or an electrically heated coil radiated normally downward to orizontal sample surface. A similar observation was described by Gardon) who measured temperature of wood heated by a solar furnace. There- there are serious questions of the assumption of the constant radiation to the sample surface after the sample starts to decompose. While work is theoretical, its importance is great to the basic understanding re spread between structures over a defined gap.

: "Effect of Attenuation of Radiation on Surface Temperature for
Radiative Ignition."

r: Takashi Kashiwagi

ization: National Bureau of Standards

ographical Data: Takashi Kashiwagi, "Effects of Attenuation of Radiation rface Temperature for Radiative Ignition," Combustion Science and ology. 1979, Vol. 20, pp. 225-234.

ry:

The effects of the attenuation of the initial radiation by the decom- ion products in the gas phase on surface temperatures of PMMA and red ere studied by using a CO_2 laser in the initial radiant flux range from 18 W/cm^2 irradiating normally downward to the horizontally mounted e.

The quantitative relationship between the attenuation of the initial tion by the decomposition products and the initial radiant flux was ed empirically and was roughly expressed by an exponential relation. the transmittance through the plume of the decomposition products de- es rapidly with time after the decomposition starts at the high initial nt flux, the high initial radiant flux does not necessarily mean higher ent flux on the sample than that at the low initial radiant flux. ally, the former becomes lower than the latter some time after the position starts.

The surface temperature of PMMA rises to about 400°C during the pre- ion heating period and the maximum surface temperature tends to be endent of the initial radiant flux. However, the maximum surface rature of red oak during the preignition heating period tends to ase with decrease in the initial radiant flux. At the low initial

.iat flux, surface temperature rises higher than that at the high initial .iant flux. These trends are explained by the attenuation of the .tial radiation coupled by the decomposition mechanisms of both samples .h as fairly narrow range of decomposition temperature of PMMA and the ıpeting decomposition processes of the char formation and gasification red oak controlled by the heated rate.

Surface temperature at ignition of PMMA is in the range of 375 to 410°C l remains fairly constant from 8 to 19 W/cm^2 for piloted-igniton and auto-ıition. Surface temperature at ignition of red oak increases from 400°C 16 W/cm^2 to 575°C at 8 W/cm^2 for auto-ignition and from 420°C at 15 W/cm^2 500°C at 7 W/cm^2 for piloted-ignition. Therefore, the validity of suming a critical surface temperature at ignition depends on the material l its decomposition mechanism.

AD-A155 825 CONFLAGRATION ANALYSIS SYSTEM II: BIBLIOGRAPHY(U) INTERNATIONAL ASSOCIATION OF FIRE CHIEFS INC WASHINGTONDC H HICKEY APR 85 EMW-C-0743 2/2

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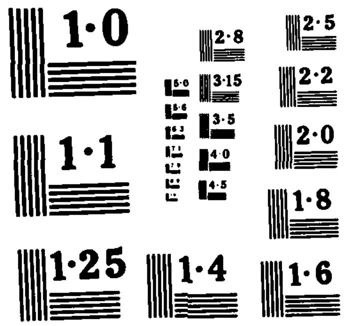
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Conflagration Analysis Study
Part II

Short Description: Simple 1/16 scale structural fires, employing models fabricated from particle board, were used to assist in the predictability of mass-fire dynamics. Nine-unit array tests of simultaneoulsy burning models were conducted as part of this program. The rates of fire development for the outer eight and for the center models in the array burns were evaluated separately. Models were also burned singly to evaluate the effects of the following parameters on the fire growth and spread in buildings: (1) single and multiple ignitions within the building, (2) combustible ceiling materials and room contents, and (3) structural blast effect.

Title: Modeling Individual and Multiple Building Fires

Author: B. T. Lee

Organization: Stanford Research Institute

Bibliographical Data: B. T. Lee, Modeling Individual and Multiple Building Fires. Menlo Park, (CA): Stanford Research Institute, DCPA Work Unit 2561H, SRI Project PYU-8150, 1972.

Summary:

The large fires that are expected to follow nuclear detonations over a city would produce an environment hostile to the surviving population, would threaten the security of fallout shelters, and would impede the conduct of vital emergency operations. To prepare for such eventualities, civil defense planning should be based on as extensive a knowledge of the mass-fire environment as possible. More information from both individual and multiple-unit arrays of simultaneously burning buildings is necessary to adequately describe these mass-fire conditions. Factors such as high cost and increasingly stricter controls on atmospheric pollution render infeasible any full-scale simulation of this fire environment. For these reasons, reduced-scale models must be fully exploited in the study of mass-fire phenomena.

From this investigation the following significant results were obtained:

(1) Increasing the fuel in the ignition room of the model shortens the burn duration but does not increase the peak rate of burning.

(2) When fire is initiated in four or more rooms in the model, the burn duration decreases and a higher peak fire intensity results.

(3) The influence of added room contents on the overall firespread in a model building is altered by materials that inherently smolder; a change that may result because the smoldering material is able to deplete the local oxygen supply even in a relatively well-ventilated enclosure.

(4) The use of combustible ceiling materials that are easily penetrated by fire can materially reduce the time for overall fire development through model structures.

(5) In model structures that simulate damage from blast overpressures, the fire intensity decreases with increased structural collapse.

(6) When a large group of buildings is burning simultaneously, a significant mutual enhancement of the individual burning rates occurs.

Result (2), although reasonable, is in direct contradiction with the results of a single similar full-scale test. No full-scale data exist to test results (1) and (6), and the evidence in support of (3) is indirect. While there is agreement on the remaining points, the similarity in model and full-scale results on effects of blast damage are, at best, qualitative.

In its present stage of development, empirical modeling of structural fires is unable to predict with full confidence the outcome of untested situations. More theoretical work is required on modeling principles if they are ultimately to serve as a trustworthy basis for model design. In the meantime the goals of empirical modeling should not be allowed to become overly ambitious. Small-scale modeling of gross interactions of building fires with the wind field and, possibly, with each other may be a realistic goal. Studies of the details of fire growth and spread should probably be reserved for full-scale testing except for idealized simulations conducted at somewhat reduced scale whenever the small loss in reliability or fidelity is offset by the practical advantages.

Conflagration Analysis Study
Part II

Short Description: Strict application of the theory governing ignition by radiation would demand tedious calculations to determine distances between buildings sufficient to prevent fire spread. The author proposes simple formulae that can be used with relative ease to estimate safe separation distances.

Title: Approximations for Spatial Separation

Author: G. Williams-Leir

Organization: Division of Building Research, National Research Council (Canada)

Bibliographical Data: Fire Technology, Vol. 2 2, May 1966.

Summary:

The authors present a computational chart for assessing "Safe Distances Between Buildings to Prevent Fire Spread by Radiation." Table 1 (attached) actually is a computation of B values for the formula d = B / hw where: B is separation parameter, h equals the height of the building, and w the width of the building.

The authors note that to use the reference Table, one must first calculate the width to height ratio fo the exposing facade. The process continues by requiring a measure of the area of windows or other unprotected openings; this is to be expressed as a per cent of the facade area. Also it is necessary to assess whether the exposing building represents a high or low hazard. Next, it is necessary to locate the percentage of windows in the appropriate hazard column, and read B in the column that corresponds to the width to height radio.

In the computed Table, B represents a parameter function that is based on the separation distance divided by the square root of the height times the width of the facing building. Inversely speaking, the B values may be assessed as a relative measure of exposure probability based upon hazard levels and width to height ratios. This concept may be very important in establishing numerical values for assessing fire spread between block fronts.

It is important to note that the separation distance Table structured in N.F.P.A. Standard No. 80 appears to be based on this study investigation. Furthermore, the simplied formula method established by David Egan also is based on this primary investigation.

Conflagration Analysis Study
Part II

Short Description: This is a thoeretical study of fire storms as developed and measured through modeling. A correlation analysis is developed between the models and the fire storms reported in Germany during World War II.

Title: Firestorm Analysis

Author: T. E. Lommasson, J. A. Keller and R. G. Kirkpatrick

Organization: Dikewood Corporation

Bibliographical Data: T. E. Lommasson, J. A. Keller and R. G. Kirkpatrick. Firestorm Analysis. Albuquerque: The Dikewood Corporation, 1977. Prepared for Division of Fire Research, U. S. Forest Department.

Summary:

The fire storm phenomena is studied using forest products to develop a theoretical model of large scale fire behavior. The fire storm is characterized by high inflow winds generated by the fire (i.e. greater than 60 miles per hour) that are independent of any natural wind velocity and a developing vertical vortex that lifts brand to heights of 5000 feet or more. The lifted brands then float on horizontal air currents to "rain down" on areas many miles remote from the initial fire zone.

The stated study also provides some correlations between the fire storm phenomena as exhibited in the natural cover fuel load studies and fire storms generated during World War II. Results of this comparative analysis have some important implications for measuring the fire spread potential between urban blocks across a defined street gap. The following considerations have been factored out of this study for proper consideration in developing the spread model between blocks.

1. The inflow convection velocity for a fire storm ranges from 58 to 93 miles per hour. Fire streams in this velocity path are useless because of the wind patterns.

2. The input convection velocity provides fresh air (oxygen) for the excellerated burning phase.

3. Once the vortex is formed in a mass fire, the radiant spread rate is significantly diminished or slowed.

4. All combustibles within the vortex ground area are consumed; no life is possible.

5. Fire brands being transmitted to remote sites present a conflagration spread characteristic not identified in the mass fire spread modeling.

Conflagration Analysis Study
Part II

<u>Short Description</u>: The danger of fire being transmitted from building to building was recognized many years ago but only recently (post 1970) have objective studies been attempted to quantify the problem and to propose quantitative solutions. It is the purpose of this text material to discuss some of the problems of fire transmission between buildings, and to outline the methods used for assessing the risk involved and the construction techniques available for protecting buildings which may be exposed to fire.

<u>Title</u>: <u>Fire and Buildings</u>

<u>Author</u>: E. W. Marchant (ed).

<u>Organization</u>: University of Edinburgh

<u>Bibliographical Data</u>: Eric W. Marchant (ed). <u>A Complete Guide to Fire and Buildings</u>. Great Britain: Harper and Row Publishers, Inc. Barnes and Noble Import Division, 1973.

Summary:

The radiation hazard presented by a building is a function of the fire load density of the combustible contents and the ventilation area provided by the openings in the external wall. Within a reasonable fire brigade attendance time (British terminology) peak radiation intensity may be 4 cal/cm^{2}s. The total radiation emitted from a building is dependent on the area of openings for the largest area of external wall enclosing a fire compartment. As the maximum radiation intensity that can be received on the surface of a building is 0-3 cal/cm^{2}s (3980 BTU/ft^{2}h) a physical or spatial barrier is required to separate any two buildings in different ownerships to reduce the risk of fire transmission from building to building.

In considering the transmitting building, research has shown that the intensity of radiation emitted from a single compartment depends on the fire load and the ventilation area available. Single compartment fires become hotter and of longer duration as the fuel load per unit window area is increased up to a maximum of about 150 kg/m^2 (31 lb/ft^2). The maximum temperature attained is about 1100°C(2012°F), lower temperatures being attained with lower fire loads. With fuel loads in excess of 150 kg/m^2, the rate of burning is controlled by the ventilation, a function of the window area, so any increase in fire load then serves to increase the duration of the fire, and consequently the level of fire resistance, (fire endurance) required in the building, but would not increase the intensity of radiation emitted from the openings.

The maximum intensity of radiation emitted from the openings in an external wall is time dependent, the maximum being reached soon after the fire has reached full development. As described in the full text material, the period from ignition to full development is unique to each fire situation. Also as noted, the time factor was important in assessing the results of the large-scale series of tests known as the St. Lawrence Burns in Canada.

When analysing the radiation data the calculated peak radiation levels approached 40 and 20 cal/cm^{2}s (530000 and 265000 BTU/lf^{2}m) respectively, for buildings with highly flammable and non-combustible linings. These levels of radiation were higher than expected but on re-examination of the data it was found that radiation values did not exceed one-fifth of the peak values until at least 16 minutes had elapsed. In many fires fire-fighting will be in progress at this stage and it is possible that radiation protection for adjacent buildings could be designed on low levels of emitted radiation, i.e. 8 and 4 cal/cm^{2}s (106000 and 53000 BTU/ft^{2}h). The reported British experiments also indicate two distinct levels of radiation related to fire load density. Buildings having a fire load density greater than 25 kg/m^2 (about 6 lb/ft^2) are rated as emitting 4 cal/cm^{2}s. These radiation values have been incorporated in building regulations for the design of radiation protection systems.

It is concluded that the amount of heat radiated from the surface of a building depends on a number of factors. These are:

1. The degree of compartmentation within the building

2. The fire load in each compartment

3. The area of window, or other opening, in the external wall of each compartment

4. The calorific value of the potential fuel (i.e. combustible contents)

5. Wind conditions at the time of fire

6. Any installed fire-fighting equipment to protect openings.

Conflagration Analysis Study
Part II

Short Description: The literature implies that spatial separations based on peak radiation levels will prevent ignition by radiation, indefinitely. The specified distances, however, exceed practical limits. Separations calculated to prevent ignition by radiation long enough for fire extinguishing operations to be initiated have been tabulated. The author explains how the exposure tables were derived and discusses problems that may be encountered in their use.

Title: Fire and the Spatial Separation of Buildings

Author: J. H. McGuire, SFPE

Organization: Division of Building Research, National Research Council (Canada)

Bibliographical Data: Fire Technology, Vol. 1, No. 4, November 1965

Summary:

McGuire states that the spread of fire from one building to another building separated from the first building by a vacant space such as a street may result from one or more of the following mechanisms:

1) Flying Brands
2) Convective heat transfer
3) Radiative heat transfer

In a factor analysis it should be noted that flying brands may initiate secondary fires at substantial distances from the primary fire, e.g. at least a quarter of a mile. It is not, therefore, practical to consider the Spatial separation of buildings as a means of combating this hazard. Rather regulation of the choice of exterior cladding materials, particularly on roofs, minimizes such ignitions, and their extinguishment is usually easy, provided they are detected at an early stage.

Secondly, convected heat transfer will cause ignition only if the temperature of the gas stream is several hundred degrees Celsius. Such high gas temperatures are only to be found in or very near the flames emanating from the windows of burning buildings.

Thirdly, ignition by radiation from a burning building can occur at distances substantially greater than those to which flames generally extend. It is this radiation mechanism, therefore, that will be the factor governing the specification of the spatial separation of buildings from the fire spread concept of analysis.

This article reports that the radiation levels to be expected from burning buildings were investigated in the course of a program of full-scale

burns known as the St. Lawrence Burns, carried out by the Division of Building Research, National Research Council, during the winter of 1958. The following are the reported findings.

1) The nature of exterior cladding - brick or clapboard - did not noticeably influence radiation levels.

2) Peak radiation levels at some distance from the buildings con-insided with those that would result if window openings, at an appropraite hypothetical temperature, were taken to be the only sources of radiation.

3) Peak radiation levels from buildings with highly flammable linings were twice those from buildings with noncombustible linings.

4) Radiation levels were affected by wind conditions, those on the leeward side of a building being, in general, much greater than those on the windward side.

McGuire indicates that it is preferable to discuss the radiation question in terms of a quantity called the configuration factor rather than in terms of radiation levels, which obviously are not recorded during a fire. A configuration factor is defined as the ratio of the radiant intensity at the receiving surface to that at the (one or more) radiating surfaces and receiving surfaces. Assuming that these are at a uniform block body temperature, a configuration factor is calculated solely from the relative geometry of the radiating and receiving surfaces.

The configuration factors that would be specified on fire emanating from openings in a wall to offer protection against the peak levels of radiation measured at the St. Lawrence Burns would be 0-3/40 = 0.0075 (hazardous case) and 0.3/20 = 0.015 (normal cases). To guard against radiation levels of about one-fifth the peak value would call for configuration factors of 0.035 (hazardous cases) and 0.07 (normal cases)

Tables 2 and 3 from the McGuire paper are attached to illustrate samples of calculations based on configuration factors of 0.035 and 0.07 respectively, for particularly hazardous and normal conditions. In other words, the specified separations theoretically reduce the radiant intensity at an exposed building to 0.035 or .07 times the equivalent intensity at the window openings of the exposing building.

The stated table appear very useful in developing a new analytical approach to the quantification of fire spread between structures.

Conflagration Analysis Study
Part II

Short Description: This is a very theoretical piece dealing with heat transfer by radiation. The expressions are derived by means of which the radiation intensity at a point due to various shapes of heated surface may be computed. The expressions are concerned only with the relative geometry of the surface and are known as configuration factors. the various properties of configuration factors are listed in tables. Total radiation flux over a finite area of a receiver is also considered.

Title: Heat Transfer by Radiation.

Author: J. H. McGuire

Organization: Department of Scientific and Industrial Research, London.

Bibliographical Data: J. H. McGuire, Department of Scientific and Industrial Research and Fire Offices' Committee, Charles House, London; Special Report No. 2, 1972.

Summary:

It is the premise of this paper that a knowledge of the radiative transfer between two surfaces is necessary in the approach to the spacing of buildings to ensure adequate separation in the event of fire. The laws of thermal radiation are treated in most test-books on heat, which demonstrate, for example, that the radiation intensity from a surface depends on the nature of the surface and on the fourth power of its absolute temperature, and that the transfer to a receiving surface depends on the geometrical relationship between radiator and receiving element.

A term known as a configuration factor, or geometrical factor, is used to take account of the geometrical relationship between a radiator of uniform temperature and emissivity and a receiving element. It may be defined as the ratio of the intensity at the receiving element to the intensity near to the radiator and is a function of the size of the radiating surface, its distance from the receiving element, and the relative orientation of the receiving element and radiator. Its value varies from zero to unity depending on whether the receiving element is at a great distance from the radiator or whether it is so close that the radiating surface subtends a solid angle of 2.

It is further noted that when dealing with problems in which the emissivity factors of either the receiver or the radiator differ appreciably from unity, the effect of multiple reflections can be an important factor influencing the net rate of gain of heat by the receiver.

A generalized consideration of the problem would include the following effects:

a. Reflections between different portions of any one surface.

b. Reflections between the two surfaces.

c. Reflections between each surface and any other surface if the radiator and receiver do not comprise an enclosure.

No attempt is made in this paper to derive a general expression including all these effects but solutions are given where (a) and (b) are involved, and for the general case involving (b) only.

The following assumptions are made:

(1) The radiation intensities are uniform over the two surfaces considered.

(2) Reflections are diffuse and that reflected radiation has a uniform angular distribution that must be accounted for in any computations.

Finally, irrespective of the type of reflections involved, radiation intensities will be the sum of one or more infinite series of defined variables. The end problem is to simplify the series for practical understanding.

onflagration Analysis Study
art II

hort Description: This standard outlines recommendations that are aimed t protecting combustibles within, and on the exterior of, an exposed uilding. The standard is applicable to the considerations associated ith fire spread from buildings in a given block configuration to uildings in adjacent blocks. The standard clearly defines the factors nvolved and the operational considerations associated with fire spread cross intervals of space.

itle: National Fire Protection Association, Standard 80A - Protection from Exposure Fires.

uthor: N.F.P.A.

rganization: National Fire Protection Association

ibliographical Data: National Fire Protection Association. Standard 80A, rotection from Exposure Fires. 1980

ummary:

It is important to understand the terminology and concepts associated with the stated standard. It is also important to understand the measures of exposure severity used in the standard. These concepts are key to formulating an anyletical approach to fire spread between structures across block fronts. The significant features of the standard that appear applicable to fire spread between block areas follow:

There are two basic types of exposure conditions to be considered. First, there is the problem of exposure due to radiated heat. The type of radiation may be a product of:

1) Heat passing through windows or other openings in the facade of a burning building.

2) Heat from the flames issuing from the burning facade of a building, or

3) Heat from the flames issuing from the windows of a burning building.

Second, is the relationship of the heights of exposing buildings. The basic concern relates to the exposure to flames issuing from the roof or top of a burning building in cases where the exposed building is higher than the burning building.

The concept of pilot ignition is also important to a proper understanding of the potential ignition of exposed structures. This involves the radiant ignition of a material by radiation where a local high temperature igniting source is located in the stream of gases and colatiles issuing from the exposed materials. In practice, a glowing ember or a flash of flame might constitute the high temperature ignition source which merely serves to ignite the flammable gases and volatiles.

It is important to understand that the mechanism differs from spontaneous ignition by radiation in which there is no local high temperature igniting source and for which higher intensities of radiation are required.

Fire severity related to exposure is a description of the total energy of the fire. It involves both the temperatures developed within the exposing fire and the duration of burning. In Standard 80A there is a description of three levels of exposure severity as light, moderate, or severe. The classifications are based upon (1) the average combustible load per unit of floor area and (2) the characteristics of an average flame spread rating of the interior wall and ceiling finishes. Tables 5-3A and 5-3B taken from the N.F.P.A. material serve as a guide in assessing severity on the basis of these properties. In using these tables, the more severe of the two classifications should govern. (Tables are attached)

The standard clearly points out that besides the temperature and duration of the exposing fires, other variables influence the severity of exposure on buildings. Some of these variables include the following:

Exposing Fire:

1) Type of construction of exterior walls and roofs.
2) Width of exposing fire.
3) Height of exposing fire.
4) Percent of openings in exposing wall area. Exterior walls that are combustible or which do not have sufficient resistance to contain the fire should be treated as having 100 percent openings.
5) Ventilation characteristics of the burning room.
6) The fuel dispersion, or surface volume ratio of the fuel.
7) The size, geometry, and surface to volume ratio of the room involved.
8) The thermal properties, conductivity, specific heat, and density of the interior finish.

Exposed Buildings

1) Type of construction of exterior walls and roofs.
2) Orientation and surface area of exposed exterior walls.
3) Percent of openings in exterior wall area.
4) Protection Openings
5) Exposure of interior finish and combustibles to the radiation, convection, and flying brands of the exposing fire.
6) Thermal properties, conductivity, specific heat, density, and fuel dispersion of the interior finish materials and the building contents.

Site and Protection Features

1) Separation distance between exposing and exposed buildings.
2) Shielding effect of intervening noncombustible construction.
3) Wind direction and velocity.
4) Air temperature and humidity.
5) Accessibility for fire fighting operations.
6) Extent and character of fire department operations.

Trees in each of the 14 selected areas were lifted, transported, and ed to furnish the fuel for burning. The job of plot preparation was dled by a private contractor. The test fuel beds were built by arrang- pinyon pine-juniper trees in piles covering about 2,000 square feet and nding 6 or 7 feet tall. After fuel piles were completed, they were left dry. Plots were to be burned when their average moisture content roximated that of wood in buildings. Before burning, each plot was vily instrumented to measure characteristics of the fire and its ironment.

The following conclusions were drawn on the basis of the work done:

1. Experience to date in preparing, conditioning, and burning experimental fires using pinyon pine-juniper debris has been favorable. The debris dried rapidly, permitting early burning. Weather conditions were not particularly a problem in the field work.

2. Some difficulty was encountered in writing the clearing contract and communicating with prospective bidders so as to get the results wanted. In future work of this type, extreme care should be taken in writing the contract requirements so that they are unambiguous.

3. The existing tree weight-crown diameter relationships for pinyon pine and Utah juniper may be directly applicable to these and to other species of pinyon pine and juniper growing elsewhere in the Southwestern United States.

4. Good aerial photos are essential for selecting sites and prospective plot areas.

5. The technique of clearing the individual types of equipment and equipment teams developed and used by the contractor appeared to be equal to the job.

ɔrt Description: Includes three reports: Preparation of Test Plots r Fire Behavior Studies Using Wildland Fuels to Simulate Urban ıditions," by Theodore G. Storey; "Three Weights and Fuel Size stribution of Pinyon Pine and Utah Juniper," by Theodore G. Storey; ı "Gas Analyses in Large Fire Experiments," by A. F. Bush, J. J. ɔnard, and W. H. Yundt. Report work done as part of Project ambeau, an investigation of mass fire conducted by the Pacific South- st Forest and Range Experiment Station and sponsored by the Office ɔf vil Defense, Department of the Army and the Defense Atomic Support ency, Department of Defense.

tle: Project Flambeau: An Investigation of Mass Fire - Volume II

thor: Theodore G. Storey, et. al.

ganization: Pacific Southwest Forest and Range Experiment Station

bliographical Data: Theodore G. Storey, A. F. Bush, J. J. Leonard, d W. H. Yundt. Project Flambeau: An Investigation of Mass Fire (1967-69). Final Report - Volume III and Appendixes. Berkeley: Pacific uthwest Forest and Range Experiment Station, 1969 (OCD Work Unit 36-A.

mmary:

Studies in forest fire behavior by the Pacific Southwest Forest and nge Experiment Station have included a series of experimental fires made r the U.S. Defense Atomic Support Agency and U.S. Office of Civil Defense. les of uprooted pinyon pine and Utah juniper were set up, dried, instru- nted, and then burned at a test site along the California-Nevada border. e piles represented fuel loading and spacing of houses in residential eas of typical cities in the United States. In each plot, the piles were nited simultaneously so as to obtain a high-intensity fire.

In the 1964-67 experimental fires, the Station used some unique methods select the test site, clear the land, prepare the plots, and determine e amount of fuel. By using entire trees for fuel, including roots, the st of gathering fuel was reduced markedly. This paper describes the thods used and includes recommendations of what might be done in future rk of this type.

Candidate test sites within the pinyon pine-juniper type were chosen ter a reconnaissance survey from light aircraft, study of aerial photos, d follow-up ground inspection. Two sites were selected: the 45,000-acre salt Site north of U.S. Highway 6 and west of Basalt, Mineral County, vada; and the 15,000-acre Mono Site south of California Highway 31, no County, along the California-Nevada border, and northeast of Lee Vining, lifornia. After the sites were chosen, three stands were tentatively tched with plot fuel requirements.

The ultimate goal of continued testing would be to develop a model of the radiation and convective heat transfer from flames emerging from a window to a wall of specified surface flammability properties and to calculate the separation distances required to prevent ignition for any window and wall arrangement.

This difference in fire room temperatures, during the early test stage, could have been created by variations in the wood crib stack height, changed geometric configuration, radiation absorption and initial heat release, etc.

Ignition of the exterior plywood panels located 1 ft. from the edge of the window in a reentrant corner did not occur due to the burning of a room fire load of 4.4 pounds per square foot of floor area. However, surface charring occurred and peak surface temperatures of 350°C (660°F) were measured. When the fire load was increased to 6.3 points per square foot, and air was continuously introduced into the burn room, surface ignition took place at 9 minutes on the plywood in the vicinity of the window opening.

The incident irradiance and the total amount of heat energy absorbed at the exposed surface of the east plywood wall prior to ignition were estimated to be approximately 1.0 W/cm^2 and 175 J/cm^2 respectively.

Conflagration Analysis Study
Part II

Short Summary: As a part of the research program concerning the recommended criteria for fire safety in Operation BREAKTHROUGH, two full scale fire tests were performed on a mockup of a reentrant corner, i.e. the interior corner formed at the intersection of the exterior walls of adjacent buildings, such as townhouses and garden apartments. The radiant heat flux incident to the adjacent walls was measured as a function of time to in fact predict the exposure ignition time. This concept appears to be most important relative to a total conceptual framework of fire spread between block fronts.

Title: "Fire Spread on Exterior Walls Due to Flames Emerging From a Window in Close Proximity to a Reentrant Wall Corner."

Author: B. C. Son and J. B. Fang

Organization: National Bureau of Standards

Bibliographical Data: B. C. Son and J. B. Fang, "Fire Spread on Exterior Walls Due to Flames Emerging From a Window in Close Proximity to a Reentrant Wall Corner," Washington, D.C.: Center for Building Technology, Institute for Applied Technology, National Bureau of Standards, PB 225-286, April 1973.

Summary:

In each test, two wall speciments representing exterior walls were erected perpendicular to a wall containing a window opening into a fire room. One wall was located 1 foot east and the other one 5 feet west of the edges of the window. The objective of the reentrant corner fire test was to study the potential ignition and spread of fire from the room to an adjacent exterior combustible wall.

In the first tests, charring on the east wall, but no surface ignition was observed during the test. The peak temperature measured did not exceed 350°C (660°F). In the second test, surface ignition occurred on the east wall 9 minutes after the wood crib, representing the combustible contents of the room, was ignited. No significant changes were observed on the west wall during either test.

The instantaneous heat flux incident on the east wall just prior to ignition and the total heat energy absorbed were estimated to be on the order of 1.0 W/cm^2 and 175 $Joules/cm^2$ respectively.

Since there was no ignition of the exterior plywood (flame spread index 103) on the west wall (4-1/2 to 5 feet from the opening) for either fire load and since there was ignition of the plywood on the east wall (1 foot from opening) for only the higher fire load it would appear that the choice of a limiting flame spread index of 75 for the exterior combustible wall surface material in a reentrant wall corner configuration was a sound technical judgement. However, to refine this index, additional testing and analysis involving variations in the window to wall separation distance and wall materials would be required.

Conflagration Analysis Study
Part II

Short Description: Material published in Smith and Harmathy provide an important dimension to the subject of conflagration analysis. The information sited in the summary is important to an appreciation of the variables that impact on conflagration potentials. The analytical concepts associated with the following review are also important to a complete understanding of the conflagration potential in orban areas.

Title: Design of Buildings for Fire Safety

Author: Smith and Harmathy, Editors

Organization: American Society for Testing Materials

Bibliographical Data: E. E. Smith and T. Z. Harmathy, "Design of Buildings for Fire Safety." (A symposium sponsored by ASTM Committee E05 on Fire Standards American Society for Testing Materials, Boston, Mass., 27 June 1978). American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa. 19103.

Summary:

The material presented indicates that the concern for potential conflagrations has been confined to mass urban burn fires. In a mass urban fire, wood frame construction and strong wind conditions usually combine to yield a large area fire. Examples are cited to support this contension. Winds and wood shingles combined to destroy 1600 buildings in Salem, Mass. in 1914 and 680 buildings in Augusta, Ga. in 1916. Strong winds also propagated the great fires of St. John (Canada, 1877), Chicago in 1971 and London in 1666. It is reported that the great fire of London burned for five days and destroyed fifteen thousand houses and eighty-four churches. In these fires fire brands carried by the high winds were significant in causing further ignitions and spread. Even in the recent times urban fires have occurred under similar conditions. The fire in Chelsea, Mass. in 1973 which was nearly identical to a fire in 1908 was swept by high winds through congested wood frame housing. It destroyed a seventeen block area. Radiation and fire brands were significant factors in the spread of the Chelsea fires. Even a "firestorm" was said to have originated. A 'firestorm" refers to a large mass fire which causes high entrainment of air near the base of the fire column such as that experienced in a storm - velocities of 1[illegible] feet per second as stated by Baldin and North. They also suggest a minimum area for a firestorm of about 1/2 miles. Although people experienced difficulty in walking away from the Chelsea fire into the wind, it does not appear to measure up to the Baldwin-North Criterion for a firestorm.

Short Description: The identified text is a collection of articles translated from the Russian literature. One particular piece on the rate of heat transfer between flaming bodies has implications for the study of mass fire development between structures. In essence it is noted that the structural configuration of the combustible materials has considerable effect on the combustion process especially the macrostructure (i.e. the physical size of the combustible materials) and their distribution in space.

Title: Problems in Combustion and Extinguishment

Author: I. V. Ryabov, A. N. Baratov, and I. I. Petrov

Organization: Published by the National Bureau of Standards

Bibliographical Data: I. V. Ryabov, A. N. Baratov & I. I. Petrov. Problems in Combustion and Extinguishment. (Translated by: K. L. Awasthy) Springfield, (VA): National Technical Information Service, 1974.

Summary:

The material presented relevant to fire spread between structures can best be summarized as a series of specific points as follows:

1. The dominant factor in fire spread is a function of the surface-to-volume ratio of the combustible material.

2. The second most important factor in fire spread is the density of the fuel material.

3. There is a linear relationship between the degree of fuel break-up and the rate of combustion transfer to adjacent bodies.

4. The upper limit (of the transfer distance) depends upon the size of the particles of combustible material: the bigger the particles, the more distance that is overcome by the flame front.

5. From experiments, it can be concluded that voids (spaces) between burning and non-burning materials (combustible) can be divided, according to three functional relationships:

   a. Small separations (with 5.0 m or less) which is found to be occupied mainly by combustible gases that provide the ignition wave;

   b. Average separations through which oxygen can flow to the adjacent layer of the combustible material during the combustion plase with an active flame;

   c. Large separations which act as barriers for the spreading of flames solely through radiant transfer.

emissive power of the flames above the window would permit the prediction of radiative flux at a distance.

These experiments were probably performed to reaffirm the maximum effective window radiation flux of 16.7 W/cm^2 specified in a design criteria for determining minimum safe distance between buildings.

Conflagration Analysis Study
Part II

Short Description: Emphasis is placed on the interaction of building geometry and building meterials and their relationship to fire spread from both compartments and buildings. Examples are given in which mathematical design procedures or analysis could determine a fire safety design to limit fire spread. The concepts associated with fire spread between buildings is of special interest to the fire spread study between blocks in an urban area.

Title: "The Spread of Fire From a Compartment - A Review"

Author: James Quintiere

Organization: American Society of Testing Materials

Bibliographical Data: Quintiere, James, "The Spread of Fire from Compartment - A Review," Design of Buildings for Fire Safety. ASTM STP 685, E. E. Smith and T. Z. Harmathy, Eds. American Society of Testing Materials, 1979, pp. 139-168.

Summary:

Quintiere states that back in 1958 the National Research Council (Canada) conducted a number of fire experiments in buildings in the town of Aultville. One objective was to study the radiation from these building fires as a function of interior lining material and external cladding. The results clearly indicated that the radiation emitted from the window and external flame depended on the wind conditions, but was not strongly dependent on the external cladding material. The radiation level did not attain a maximum for at least 16 minutes after ignition, and did not exceed one-quarter of its maximum value within 16 minutes. Radiation measurements were reduced based on the assumption that radiation is emitted from the window alone. In this form, rooms with combustible linings yielded a maximum of 167 W/cm^2 compared to 84 W/cm^2 for a measured maximum room temperature of 1000°C. Hence a significant portion of radiation resulted from the external flame.

This study notes that while conclusions from the stated tests showed that external flame radiation is significant, this concept was later discounted by M. Law. The results of her study show only a small radiation contribution from the external flame above the window. However, it should be noted that Law also found the effect of a combustible internal lining could be significant in producing increased radiation levels. Furthermore, the maximum effective window emitted radiation was 24W/cm^2 - far less than that recorded in the Aultsville experiments. The high flux values in the Autsville experiments were attributed to wind effects and drafts through the buildings. Also, the window flux correlated very well with the maximum compartment temperature by assuming the window radiated as a blackbody at that temperature. Thus the compartment temperature together with the

Conflagration Analysis Study
Part II

Short Description: Summarizes, in catalogue form, the data available from nine experimental fires conducted from 1964 to 1967 by Project Flambeau, a research activity of the Pacific Southwest Forest and Range Experiment Station. The fires were burned as part of an investigation of mass fire sponsored by the Office of Civil Defense, Department of the Army and by the Defense Atomic Support Agency, Department of Defense and DASA. The types of data available, their form and where they are on file are listed.

Title: Project Flambeau: An Investigation of Mass Fire - Volume II

Author: Thomas Y. Palmer

Organization: Pacific Southwest Forest and Range Experiment Station

Bibliographical Data: Thomas Y. Palmer. Project Flambeau: An Investigation of Mass Fire (1964-1967); Final Report - Volume II. Berkeley: Pacific Southwest Forest and Range Experiment Station, 1969 (OCD Work Unit 2536-A)

Summary:

This report summarizes, in catalogue form, the data available from nine experimental fires conducted by Project Flambeau from 1964 to 1967. The fires were burned as part of an investigation of mass fire sponsored by the Office of Civil Defense, Department of the Army, and by the Defense Atomic Support Agency, Department of Defense, Washington, D.C.

Project Flambeau was research activity of the Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Berkeley, California. Before July 1966, Project Flambeau was known as the Fire Behavior Project of the Station.

The designations for the nine fires and the dates they were burned were:

Experimental Fire	Date
760-1-64	January 31, 1964
760-2-64	May 15, 1964
760-3-65	June 11, 1965
460-14-65	December 6, 1965
460-7-66	June 14, 1966
SR-3-67	June 8, 1967
SR-5-67	August 10, 1967
760-12A1-67	August 29, 1967
760-12-67	September 29, 1967

For each fire, this report provides information on (a) test data, (b) project number, (c) project officer, (d) types of measurements, (e) photography, (f) security clearance, (g) volume of records, (h) date of release, and (i) cooperative studies.

Conflagration Analysis Study
Part II

Short Description: Knowledge of the level of fire risk in various occupancies is of use in assessing the probablity of fire spread. This paper examines four important parameters relating to fire risk: 1) the probability of fire per establishment, 2) the expected loss per establishment, 3) the risk of personal injury, 4) the risk of death by fire in various occupancies.

Title: The Estimated Fire Risk of Various Occupancies

Author: M. A. North

Organization: Fire Research Station, Borehamwood

Bibliographical Data: M. A. North, The Estimated Fire Risk of Various Occupancies. Fire Research Station, Borehamwood, Hertfordshire, Wd6-2BL, F. F. Note No. 989, October 1973.

Summary:

Two Tables are "Key" to this research study. Table 1 sets forth eight risk parameters for measuring potential loss based on manufacturing industries. These parameters are translated into "Estimates of Fire Risk" and presented in Table 2. Estimates of fire are established as follows:

1) Probability of an outbreak of fire. The number of fires per establishment per year.

2) Expected loss. The mean estimate direct fire loss per establishment per year. Since loss figures are only available for those fires in which the loss was 10,000 pounds or more and such large fires account for about 65 per cent of all fire losses, the loss figures presented in Table 1 have been multiplied by a factor of 100/65 before calculation of the mean loss. Some occupancies deviate markedly from this distribution and the calculation gives meaningless figures, so arbitarily, occupancies in which less than 1 fire in every 100 reported to the brigade has an estimated direct loss of 10,000 pounds or more, have not been included.

3) Injury Risk. The probablity of a person suffering non-fatal injuries from fire per unit time spent in that occupancy.

4) Fatality Risk. The probability of a person suffering non-fatal injuries from fire per unit time spent in that occupancy.

The value of this study t mass fire analysis is simply the relative measure of risk by occupancy classification. This material will cross correlate to the occupancy factors in the revised methodology.

Conflagration Analysis Study
Part II

Short Description: This piece of research transposes experimental work done on forest fire behavior to urban mass fire development. This program was initiated to investigate the origin and properties of fire whirls because of their possible occurrence in large urban fires. In such fires, the whirls could significantly affect life safety, fire spread, and rescue and damage control activities.

Title: Origin and Properties of Fire Whirls
Author: Hugo J. Nielsen
Organization: Illinois Institute of Technology Research Institute

Bibliographical Data: Hugo J. Nielsen, Origin and Properties of Fire Whirls, Chicago: Engineering Mechanics Division, Illinois Institute of Technology Research Institute, 1969 (Project J6129 - Work Unit 2536H)

Summary:

Since fire whirls require a rotating environment to exist, the problem of the origin of fire whirls is the problem of the origin of rotation or vertical vorticity, in fires. Several mechanisms were considered which were thought to be capable of developing vertical vorticity. The distribution of vorticity that would result from these mechanisms was then compared with the circulating flow patterns shown to exist in experimental fires. Of these mechanisms, the bending upward of horizontal vortex lines yielded vertical vorticity of largest magnitude for the conditions of the experimental fire. The intensity and pattern of distribution over the fuel bed is also in good agreement with experimental fire data. From this result, a procedure was worked out for predicting the intensity of fire whirls in urban fires. The procedure is based on the way the production of vertical vorticity scales with the size and heat output of the fire and theoretical solutions for a convective vortex.

3. The first material ignited should be identified and characterized as to chemical and physical properties.

4. Other fuel materials that play a significant role in the growth of the fire should be identified and described.

5. The path and mechanisms of fire growth should be determined. Particular attention should be given to fuel element location and orientation, ventilation, compartmentation, and other factors that affect fire spread.

6. The possible role of smoke and toxic gases in detection, fire spread and casualty production should be determined.

7. The possibility of smoldering combustion as a factor in the fire incident, e/g. as a cause of re-ignition, should be considered.

8. The means of detection, the time of detection, and the state of the fire at the time of detection should be described.

9. Defensive actions should be noted and their effects on the fire, on the occupants, and on other factors should be described.

10. Interactions between the occupants of the building and the fire should be detailed.

11. The time sequence of events, from the fire occurrence of the ignition flux to the final resolution of the fire incident, should be established.

This material is important for the scenario should permit generalization from the particular inicdent described. It should provide a basis of exploration of alternative paths of fire safety performance of changes in materials, design, and operating procedures.

Conflagration Analysis Study
Part II

Short Description: This published work is on fire dynamics. In an effort to clarify the understanding of the phenomena accompan,ing fire, consideration is given in this test to the mechanics of mass and energy transfer in structures and between structures. The later concepts are important to the assessment of fire spread between block fronts.

Title: Fire Dynamics and Scenarios, Volume 4.

Author: National Materials Advisory Board, National Academy of Sciences

Organization: National Academy of Sciences

Bibliographical Data: National Materials Advisory Board, Fire Safety Aspects of Polymeric Materials. Washington, D.C.: National Academy of Sciences, 1978 - NMAB 318-4.

Summary:

Where a structure becomes completely involved with fire, a finite probability exists that adjacent structures will ignite. Ultimately, a conflagration involving a large area may result. Such fire propagation could occur either by radiation or firebrands.

Potentially critical factors in the fire scenario are: magnitude and direction of the wind, separation distance between structures; flammability of roofing materials such as wood shingles, ignitability by radiation of curtains inside windows facing fire, combustible trash in alleys between buildings, and propulsion of burning debris after building collapse or explosion.

Since the spread of fire to other structures usually occurs at a sufficiently late stage of a fire, firefighters will probably be present. Their tactics in wetting down adjacent buildings appear to be extremely valuable in preventing spread to such structures. Conversely, if the fire were simultaneously burning in many areas, as could be the case for a brush fire or fire caused by civil disorders or military incendiary attack, firefighting will probably be inadequate, and the degree of spread will depend on the intrinsic "fire-hardness" of the structures involved.

Similarly, if a fire were started by the effects of an earthquake or strong explosion, water mains would probably be broken and firefighting would become ineffectual. In that case, spread would again be limited by the intrinsic "hardness" of structure involved, which is material dependent.

The National Materials Advisory Board has identified the following essential fire scenario elements in the structural fire spread phenomena.

1. The pre-fire situation.

2. The source of the ignition energy should be identified and described in quantitative terms.

This background information is culminated with a Table that sets forth Guide Numbers for Minimum Separation Distances. Table 5-3C setting forth this information is attached.

In appears possible to structure an exposure probablity evaluation procedure based upon the described indicators.

Conflagration Analysis Study
Part II

Short Description: This study involves the development of a general computer model for calculating the initiation and spread of fire from a nuclear attack on an urban area and its application to the cities of Detroit, Albuquerque and San Jose. Each city is represented by several hundred tracts which are distinguished from one another in terms of the size and composition of the built-up area and the width and length of the firebreaks to the built-up areas in adjacent tracts. Two codes are employed to evaluate the fire damage; the first computes the percent of area used to represent the city as a function of distance from ground zero; the second computes the spread of fire by radiation and firebrands within and between tracts as a function of time. Pictorial illustrations were generated for each of the cities showing the percent of buildings undamaged by fire in each of the tracts at 0, 1, 3, 10 and 28 hours after a 5 MT burst. Volume I of the report contains a description of the development of the computer model and the procurement of data while Volumes II, III and IV indicate the fire damage to the cities of Detroit, Albuquerque and San Jose, respectively, from the 5 MT burst.

Title: Development and Application of A Complete Fire-Spread Model

Author: Arthur N. Takata and Frederick Salzberg

Organization: Illinois Institute of Technology

Bibliographical Data: A. N. Takata and F. Salzber. Development and Application of A Complete Fire-Spread Model. Chicago: Illinois Institute of Technology, Technology Center, Chicago, Illinois, Final Report, June 1968, Project J6109 for the Office of Civil Defense, Washington, D.C., Work Unit 2538B.

Summary:

The objective of this study is to develop a complete model for calculating the initiation and spread of fire resulting from an attack on an urban area, and to apply the complete model in predicting the time-dependent fire damage to the cities of Detroit, Albuquerque and San Jose from a 5 MT burst. The scope of work includes the following:

"The model to be developed shall include specification of input information required, explanation and justification of the calculational and estimational procedures used, and estimation of the accuracy or credibility of the results in terms of the accuracy or credibility with which the values of the input parameters are known. This model shall take into account fire spread by radiation, by firebrands and by convective heating, and shall be capable of being used for the prediction of ignition-limit contours and of fire-limit contours at 1-hour intervals from H hour and for the production of maps of sample areas showing buildings in which sustained fires occur and the nature and extent of these fires within each building at 1-hour or smaller intervals

after H hour." The model was applied to the calculation of the time-dependent fire damage that would occur in the cities of San Jose, Detroit and Albuquerque for the attack conditions specified by OCD.

This report is prepared in 4 volumes. Volun I covers the development of techniques to determine the initiation and spread of fire in urban areas and the development of computer codes to perform the computations. Volumes II, III, and IV cover the fire damage to Detroit, Albuquerque and San Jose, respectively, at times ranging from 0 to 28 hours after a 5 MT burst.

A summary of the content of each volume follows:

VOLUME I:

Volume I covers the analysis, data and computer codes to determine the fire damage to urban areas. The urban areas are described in terms of several hundred square tracts which differ from one another according to the composition and size of their built-up area and the separations to built-up areas is described in terms of the heights, sizes and density of the buildings which in turn are used to determine the number of windows and the separations between buildings. Each tract includes a similar description of the window coverings, the window openings and the room content.

Two codes were developed to predict the initiation and spread of fire in each of the tracts. The Ignition Code predicts the precent of buildings ignited by the fireball in various categories of built-up areas as a function of the composition of each built-up area and its distance from ground zero. The Fire Spread Code predicts the spread of fire within and between tracts as a result of radiation and firebrands at intervals of 15 minutes.

VOLUME II:

Volume II describes the fire damage to the 662 tracts used to represent Detroit and its suburbs. In this city the 5MT burst occurs on the ground and ignites buildings as far as 8 miles from ground zero. The peak burning occurs approximately 2-1/2 hours after the burst at which time approximately 9.8 per - cent of the buildings are burning, 49.0 percent of the buildings have been destroyed by fire, 15.4 percent of the buildings have been severely damaged by blast and 35.6 per cent of the buildings remain relatively free of damage.

VOLUME III:

Volume III describes the fire damage to the 373 tracts used to represent the city of Albuquerque. In this city the 5 MT burst occurs at 14,500 ft and ignites buildins as far as 16 miles from ground zero. The peak burning occurs 2 hours after the burst at which time approximately 15.9 percent of the buildings in Albuquerque are on fire. Subsequently, the number of fires decreases at a modest rate to 0.1 percent at 28 hours. At this time approximately 57.0 percent of the buildings have been

Conflagration Analysis Study
Part II

Short Description: This study presents a phenomenology of fire growth and suppression within buildings and fire spread between buildings. On the basis of study findings, a computer model is developed to calculate the fraction of fires spread at various times by radiation and firebrands. This conceptual model is important to the understanding and quantification of fire spread between structures over a defined distance.

Title: Mathematical Modeling of Fire Defenses

Author: Arthur N. Takata

Organization: Illinois Institute of Technology Research Institute

Bibliographical Data: Arthur N. Takata, Mathematical Modeling of Fire Defenses. Chicago: Illinois Institute of Technology Research Institute, Final Technical Report, Project J6118, March 1969.

Summary:

This study involves the development of techniques to evaluate the effect of fire defenses on building fires caused by a nuclear burst and the incorporation of the fire-defense techniques in a fire-spread model.

The resultant computer program allows evaluation of the effectiveness of various numbers of self-help items, brigades and fire department units in suppressing and containing building fires scattered throughout a track of several thousand buildings. Preliminary computations indicate that 1/4 of the manpower available in a tract can suppress all fires created by the initial ignition of 1/2 or less of the buildngs within a few hours. Most if the manpower, particularly those in the self-help teams can be diverted to other activities after several minutes of effort. The preliminary results show that ordinary citizens with minimal instruction and training can bring about very pronounced reductions in the total fire damage. This information has applicability to the interface relationships concerning fire spread across open spaces as a function of human interaction.

This study also indicates that fire may spread from one building to another as a result of exposure to the radiation from flames or as a result of firebrands. The problem of evaluating the fire spread involves two principal steps, namely,

1) A determination of when burning buildings are most apt to spread fire following their development into stage 3 fires.

2) A determination of expected ignitions caused by radiation and firebrands from a group of burning buildings.

The final analysis is based on a knowledge of the probabilities of fire spread from building to building due to radiation and due to firebrand. These probabilities are, of course, dependent on the separation distance between the burning and unignited buildings. Most important, this study provides analytical reference for fire spread at various times by radiation and firebrands.

Conflagration Analysis Study
Part II

Short Description: Five residential structures were burned and their firebrand production was sampled by distributing plastic sheets downwind from the structures. Hot brands melted the plastic to leave holes showing their profiles in the sheet. The holes were than traced onto paper and their areas measured with a planimeter. Actual cause histories were compared to experimental results.

Title: Firebrand Field Studies

Author: Frank J. Vodvarka

Organization: Illinois Institute of Technology Research Institute

Bibliographical Data: F. J. Vodvarka, Firebrand Field Studies. Chicago: Illinois Institute of Technology, Final Technical Report J6148, 1969; OCD Work Unit 2539B

Summary:

Of the five strctures burned for firebrand production, three of the structures were standard frame construction with wood siding. The fourth was asphalt siding applied over sheet rock wich covered the original shiplap. The fifth structure was a brick veneer over a wood frame. All five structures were burned under light and variable wind conditions.

It is noted that firebrand production was greatest at the time of roof collapse. The firebrands captured ranged from smaller than match-head size to about 15 inches. These brands were classified by fractions of the standard "C" brand used for testing roof flammability. Tentative brand densities for distances to 300 ft. were determined.

Concurrently with the experimental phase, attempts were made to obtain firebrand data from accidental fires as reported by IITRI's fire consultants. Only four fires were reported, of which only two were unwanted fires. The other two were set to dispose of the buildings.

The firebrand production and the distance of travel as reported appeared to be greater than that measured at the experimental fires. This is attributed to the higher wind velopcities and to the use of water sprays to protect exposures.

A firebrand field study questionnaire was sent to the chiefs of approximately 1600 United States communities with populations over 12,000. Almost 500 replies were received, of which 268 provided detailed information.

The final reports show that geographically, the mountain states provided the fewest replies and those indicated the least difficulty with fire brands. The remainder of the country all indicated about the same degree of occurrence of firebrands.

Conflagration Analysis Study
Part II

<u>Short Description</u>: A full-scale experiment was performed to measure the effects of a debris fire a top a basement shelter. The experiment utilized a two-story, concrete block building with the fire on the second floor and the first floor sealed to simulate a below-grade shelter. Eighty small holes, totalling 20 sq. in. were drilled in the concrete second floor to approximate the effects of cracks, and provision was made to pressurize the shelter area.

The debris, containing 6 lb/ft^2 of combustibles and 3 lb/ft^2 of non-combustibles, was ignited at several locations, and burned quite violently for about one hour. At that time, the prestressed concrete roof collapsed onto the fire, reducing it to a smouldering state.

Measurements over a 22 hour period showed no detectable CO in the shelter space for pressurizations levels of 0 to 0.05 in. of water.

While this study does not appear to have a direct impact on the fire spread model, the predicability of fire spread between blocks does have a direct bearing on the protection of life through shelter programs and should be considered in the assessment process.

<u>Title</u>: <u>Full Scale Burns in Urban Areas</u>

<u>Author</u>: Frank J. Vodvarka and F. Salzberg

<u>Organization</u>: Illinois Institute of Technology Research Institute

<u>Bibliographical Data</u>: Frank J. Vodvarka and F. Salzberg, <u>Full Scale Burns in Urban Areas</u>. Chicago: Engineering Mechanics Division, Illinois Institute of Technology Research Institute, Final Technical Report - Project J6009 - OCD Work Unit 1134A, June 1969.

<u>Summary</u>:

In the event of a nuclear blast many structures would be destroyed. Others would have their integrity breached. Debris would result. Combustible materials in the form of lumber, furniture, paper and wearing apparel would be splintered, scattered, rearranged and mixed with debris. The combustion of the debris pile atop the blast resistant shelter would subject the shelter ceiling to an elevated heat flux over an extended period of time. Further, the strong shock might cause cracks in the shelter ceiling. The cracks, though minimal insofar as the structural strength is concerned, might permit toxic gases to leak into the structure. This experiment was undertaken to investigate the effects of a debris fire burning above a shelter.

The original work scope required that the experiment be performed in a structure scheduled for demolition in White Plains, New York. However, it was found to be unfeasible to do the experiment there. Consultation with OCD resulted in agreement to change the experiment site to a structure available in Waukesha, Wisconsin. The modified scope of work calls for the loading

of the shelter ceiling, "with a mixture of combustible and non-combustible material to an extent required for a medium intensity fire. Provision will also be made for introducing water on the floor slab under the debris pile. The debris will be ignited and the effects (temperature, pressure and gas composition in shelter and in fire area and temperature of the concrete slab) will be measured during 24 hours or longer. When heat transmission into the basement has become excessive or maximum, water will be pumped into half of the debris pile and the cooling effect observed for various pumping rates. The results obtained will be augmented by further tests in the laboratory to assess the effects of low and high intensity debris fires. Toxic gas concentration inside the shelter during the fire tests shall be measured and recorded. Any openings which allow toxic gases to enter the shelter shall be described in detail, as well as any openings which allow fresh air to enter the shelter to dilute the toxic gases or to carry away heated air."

Conflagration Analysis Study
Part II

Short Description: A number of full scale burns were conducted under this study to collect data profiles on the burn history of structures. This information is used to structure a basic burn-history model that can be used to compare time versus modular from ignition to burnout. The radiant energy measures logged during the study are useful for exposure fire analysis.

Title: Urban Burns - Full-Scale Field Studies

Author: Frank J. Vodvarka

Organization: Illinois Institute of Technology Research Institute

Bibliographical Data: Frank J. Vodvarka, Urban Burns - Full Scale Field Studies. Chicago: Illinois Institute of Technology Research Institute, Project J6171, OCD Work Unit 2562A, January 1970.

Summary:

Eight structures which became available during the contract period were free burned. Five of these were two and 2-1/2-story all wood residences in various states of disrepair. The others were masonry and included a concrete-block residence, a concrete-block automobile service station, and a brick restaurant. During the burns, data were collected on burning times, fire spread rates within buildings, radiation emitted, firebrand production, gas compositions within masonry buildings, and pressures developed by the fires. Particular experiments performed with each building were chosen to be compatible with the building and its surroundings.

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